ILLUSTRATIONS.

PLATES.

TEXT-FIGURES.

OCEAN MAGNETIC OBSERVATIONS

1905-1916

By L. A. Bauer, W. J. Peters, J. A. Fleming, and J. P. Ault

Passing over various subsequent expeditions, we come to the most serious and first really important undertakings for magnetic science in general, viz, those of the *Erebus*, the *Terror*, and the *Pagoda*, from 1840–45, chiefly in the southern oceans. Here we have the first elaborate attempt at determinations of the three magnetic elements at sea, the Fox dip-circle for measuring the magnetic inclination and intensity at sea having just been devised. This most carefully executed work was done under the direction of Sabine, the famous English magnetician, who did so much for the advancement of magnetic science. Not only was the work ably directed, but the commanding officers of the vessels, one of whom was Captain Ross, the discoverer of the North Magnetic Pole, were most zealous and painstaking. The attempt was made to obtain full series of observations daily, and these were secured at times under great physical difficulties, as, for instance, in the Antarctic regions. The ships were repeatedly "swung," and every attempt was made to determine accurately the deviation constants.

It will be of interest to point out in this connection that it was not alone the devising of an instrument for measuring the magnetic inclination and intensity at sea that made this memorable and remarkable work possible, but also the elaboration of the mathematical theory of the deviations arising from the unavoidable iron on board a vessel, published by Poisson a year before the inception of the survey in 1839. Working with Poisson's formulæ, Archibald Smith, at Sabine's request, put the determination of the various necessary corrections in a practical form, so that they could be successfully applied.

The expedition of the Austrian frigate *Novara* secured a valuable series of declination data while circumnavigating the globe in 1857–60.

Next were the two notable expeditions of the *Challenger* in 1872–76 and the *Gazelle*, a German vessel, in 1874–76. Both of these made observations of the three magnetic elements over various ocean regions.

Reference should also be made to the important work done by the naval services of various countries, which can not be described here in detail, and to the observations of later Antarctic expeditions, notably those of the *Discovery* and the *Gauss*.

The work of various vessels of the Coast and Geodetic Survey also deserves notice, for it was the successful inauguration of the magnetic work on these vessels, in 1903, which gave me the requisite experience for undertaking the ocean magnetic survey of the Carnegie Institution of Washington. Since 1903, these vessels have utilized every opportunity in passing from port to port, while engaged on their regular surveying duties, to determine the three magnetic elements. Thus valuable series of observations have been obtained along the Atlantic and Pacific coasts and in the Gulf of Mexico.

L. A. BAUER.

THE MAGNETIC WORK OF THE GALILEE, 1905-1908.

By L. A. Bauer, W. J. Peters, and J. A. Fleming.

GENERAL REMARKS.

The Department of Terrestrial Magnetism of the Carnegie Institution of Washington was authorized, in 1905, to undertake a magnetic survey of the Pacific Ocean, according to a plan submitted to the Institution on October 3, 1904, by L. A. Bauer and G. W. Littlehales.[1]

While the state of our knowledge of the distribution of the Earth's magnetic forces over ocean areas, owing to the paucity of precise data, was then in general exceedingly unsatisfactory, this was especially true for the Pacific Ocean, rapidly developing in commercial importance. Except for data from occasional expeditions and such as had been acquired in wooden vessels long previously, the magnetic charts used by the navigator over the Pacific Ocean depended largely upon observations on islands and along the coasts. But because of prevalent local disturbances, magnetic observations on land are frequently not representative of the true values. It was therefore impossible to make any statement as to the correctness of the charts then in use.

Professor Arthur Schuster, in a letter dated January 26, 1902, had stated:

> "I believe that no material progress of terrestrial magnetism is possible until the magnetic constants of the great ocean basins, especially the Pacific, have been determined more accurately than they are at present. There is reason to believe that these constants may be affected by considerable systematic errors. It is possible that these errors have crept in by paying too much attention to measurements made on islands and along the sea coast. What is wanted are more numerous and more accurate observations on the sea itself."

Captain Ettrick W. Creak, at one time superintendent of the compass department of the British Admiralty, in a letter dated August 31, 1904, said:

> "The North Pacific Ocean is, with the exception of a voyage of the *Challenger* (1872–76) nearly a blank as regards magnetic observations."

Professor Schuster's surmise as to the possible existence of "considerable systematic errors" in the magnetic charts for the great ocean basins has been abundantly verified by our ocean magnetic work from 1905 to the present date. When it is recalled that the ocean areas embrace nearly three-fourths of the entire surface of the Earth, it is easily understood that lack of accurate data for this portion of the globe has greatly retarded the settlement of important problems pertaining to the Earth's magnetism. Thus the demands of science, as well as those of commerce and navigation, called for a systematic magnetic survey of the oceans under the most favorable conditions and required that the work be done under the auspices of some

[1] Bauer, L. A., and G. W. Littlehales. Proposed magnetic survey of the North Pacific Ocean. Carnegie Inst. of Washington. Year Book No. 3, 1904, 269–273 (Jan. 1905). Washington. Also, somewhat abridged, in *Terr. Mag.*, vol. 9, 163–166, 1904, Washington.

research institution of world-wide standing, to secure adequate recognition for the scientific as well as the commercial aspects of the work.

Accordingly, it was considered best to undertake first a magnetic survey of the North Pacific Ocean, which was extended later to the South Pacific. In view of the newness of ocean magnetic work of the desired accuracy, it was decided to gain some experience first in a chartered vessel. After considerable advertising, conducted during the Director's conference trip to Europe, by Consulting Hydrographer G. W. Littlehales, the brigantine *Galilee* was selected as being the best vessel of those available for the proposed work. Subsequent experience showed that the choice was a good one. Cruises to the extent of 63,834 nautical miles were carried out by this vessel in the Pacific Ocean between August 1905 and May 1908.

When authority was given to include all the oceans in the general magnetic survey, it was found best to construct a vessel adapted especially to the needs of magnetic work. Thus in 1909 the non-magnetic vessel, the *Carnegie*, of which more will be said later, came into existence, and all the ocean work since 1909 has been done with her.

The account of the work done and the results of the observations made are given separately for the *Galilee* and the *Carnegie*.

DESCRIPTION OF THE GALILEE.

The brigantine *Galilee*, chartered for the period July 1905 to May 1908, was a wooden sailing vessel built in 1891 at Benicia, California, by her chief owner, Captain Matthew Turner, an experienced ship-builder. She was originally engaged in the passenger business between San Francisco and Tahiti, until crowded out by a line of steamers, since when she had been engaged in freighting between California ports and South Pacific islands. She was known as one of the fastest sailing-vessels of her size in the Pacific Ocean, her best record being 308 miles in a day with full cargo.[1]

Her length over all is 132.4 feet, beam, 33.4 feet, and depth 12.6 feet; her net tonnage is about 328 and displacement about 600. To fit her for the purposes of the magnetic expedition, the principal changes required were the substitution of hemp rigging[2] for the steel rigging, and the removal, as far as practicable, of all iron parts in the vicinity of the places of observation. The cabin space had to be enlarged for the accommodation of the scientific personnel. Furthermore, a special observing bridge, seen between the masts in the view (Plate 1, Fig. 3), was built, running fore and aft, and about 12 feet above the deck. The instruments mounted on this bridge were then, on the average, about 15 to 16 feet above the main deck and 25 to 30 feet from the remaining masses of iron, consisting chiefly of the iron bolts in the sides of the vessel. After the first cruise the observing bridge was extended, the galley removed to forward of the foremast, and some additional minor changes were made. (See Plate 2, Fig. 1.) For further information regarding dimensions and alterations of vessel, see J. F. Pratt's report on pages 128–134.

[1]While the *Carnegie* was at San Francisco in October 1916, the *Galilee* was berthed alongside the same pier. She has been converted into a 3-masted schooner, and is engaged in the Alaskan trade.

[2]This was obtained by special contract from a Philadelphia firm.

While it was not possible to convert the *Galilee* completely into a non-magnetic vessel, as would have been desirable, the changes resulted in reducing the deviation corrections, due to the disturbing influence of the remaining iron, to such an extent that the ship's so-called "magnetic constants" turned out to be smaller for this vessel, on the average, than those of any vessel on which ocean magnetic observations had previously been made (see Table 36, p. 91).

However, the corrections were still so large that it was necessary to take them into account if the scientific requirements of the problem undertaken were to be successfully met. These corrections had to be determined by special observations, made while "swinging" ship in port and at sea as often as circumstances permitted. This necessarily caused more or less delay in both the field and office work. Unfortunately, experience had also repeatedly shown that these corrections, as based on a mathematical analysis of the deviations, were troublesome to control adequately. As the corrections arise chiefly from magnetic induction in the soft-iron parts of the vessel, they are subject to various accidental conditions, such as the length of time the vessel follows any one course, or the amount of buffeting the vessel has been exposed to from the waves, etc.

The preceding paragraph shows why it was found more economical in every way to construct an entirely non-magnetic vessel specially built for the purpose when the requisite funds became available. It seemed unfortunate to introduce, in the very regions where the disturbances due to local magnetic masses are a minimum, an extraneous source of disturbance by not having an entirely non-magnetic vessel. However, conditions in 1905 did not permit our waiting for such a vessel. The attempt was accordingly made to secure magnetic data as accurately as was then possible and to solve the problem given to the Committee on Terrestrial Magnetism of the International Association of Academies in 1904 upon the proposal of the late Professor von Bezold, viz, "the determination of the best methods of making accurate magnetic observations at sea."

Further interesting information regarding the *Galilee* and organization of the work will be obtained from the charter-party (see page 8), which was drawn up with the counsel of Judge William W. Morrow of San Francisco, a trustee of the Carnegie Institution of Washington. It should be recorded here that the firm of Matthew Turner Company carried out the terms of the contract in a most faithful and agreeable manner, ever evincing interest in the successful issue of the expeditions, and always being alert and ready to keep the vessel in good repair. This was the first of many pleasant experiences had throughout the ocean work thus far with mercantile firms with whom it has been necessary, for one purpose or another, to have business relations. Hearty cooperation and general interest have been well-nigh universal.

CHARTER-PARTY OF THE GALILEE.

THIS CHARTER-PARTY, made and concluded upon in the City of San Francisco, California, this twentieth day of July, nineteen hundred and five, between MATTHEW TURNER, managing owner of the brigantine *Galilee* of San Francisco, of the net tonnage of 328 tons, or thereabouts, register measurement, of the first part, who has the right to enter into this contract, in behalf of the owners, and the Department of International Research in Terrestrial Magnetism of the Carnegie Institution of Washington, of the second part,

Witnesseth: That for and in consideration of the payments hereinafter mentioned, to be made by the said party of the second part, the said party of the first part for himself, his heirs, executors, and administrators, doth covenant and agree on the freighting and chartering of the whole of said vessel fully manned with requisite crew and master and fully equipped and furnished, to be under the control and direction and for the occupation and the use of the said party of the second part or his representatives for the purposes of a scientific voyage in the Pacific Ocean, upon the following terms, and, with the option of renewal of this charter-party for additional voyages of the same nature upon the same terms:

The said vessel shall be tight, staunch, sound, strong, seaworthy, and in every way fitted for such a voyage and properly ballasted, with non-magnetic material, subject to the inspection of the party of the second part or his authorized agent.

The said vessel shall be kept thoroughly repaired, outfitted and seaworthy throughout the period of this charter by the said party of the first part.

The said crew, exclusive of master, shall consist of two mates, six seamen, one ship's cook, and one cabin cook, all of whom shall be in all respects qualified for the full performance of the duties of their usual station on board said vessel. Their selection and the appointment of the said master shall be subject to the approval of the party of the second part or his authorized agent.

The said vessel shall be subject to be rerigged with hemp at the cost of the said party of the second part, and to have introduced such mounts for observing instruments and such changes in the cabin and elsewhere at the expense of the said party of the second part, as may be required for her better adaptation to the needs of the Expedition, provided that her trim and seaworthiness shall not thereby be altered.

In respect to the changes above provided for to adapt the vessel to the needs of the Expedition the said vessel shall be restored at the option of the said party of the first part, to her original condition, at the expense of the said party of the second part, on the dissolution of this charter-party, or on the dissolution of its subsequent renewals as may mark the close of her employment for the purposes of the said Scientific Expedition.

The said vessel shall receive on board for the aforesaid voyage the scientific instruments and whatever may be required for the purposes of the Expedition and the observers who together with the master and crew, shall be subject to the direction of the duly appointed Commander of the Expedition; and no goods or merchandise shall be laden on board said vessel otherwise than from said party of the second part or his agent, excepting the belongings and victualing which are required to be furnished by said party of the first part for the maintenance of the master and crew who belong with the vessel. It is understood that the subsistence of the cabin cook shall be provided by party of second part.

The said party of the second part agrees to pay to the said party of the first part for the use of the said vessel and her equipment, master and crew, in accordance with the stipulations above set forth, during the voyage aforesaid, in full fourteen hundred (1400) dollars per calendar month, or eight hundred (800) dollars per calendar month for the bare ship, *i. e.*, without master and crew, and in either case pro rata for any portion of a month's hire, payable monthly at the termination of each month; and also to pay all the vessel's port charges, towages, pilotages, wharfages, and consul and health fees.

It is understood that the payments under this charter-party at the rate above stipulated, shall commence on the twentieth day of July, nineteen hundred and five, and that an allowance for lay days will be paid by the charterers to the managing owner at the rate of fifteen (15) dollars a day, beginning with June fifth, nineteen hundred and five.

To the true performance of all and every of the foregoing covenants and agreements, the said parties each to the other do hereby bind themselves, their heirs, executors, administrators and assigns, each to the other, in the penal sum of amount of charter for six months.

In witness whereof the said parties have hereunto interchangeably set their hands and seals the day and year first above written.

Signed, sealed and delivered in the presence of:

Witnesses: (Signed) MATTHEW TURNER. [SEAL]

(Signed) NELSON ANDREWS. (Signed) L. A. BAUER, [SEAL]

(Signed) J. F. PRATT. *Director, Department of Terrestrial Magnetism, of the Carnegie Institution of Washington.*

According to the above charter-party, the owners supplied the sailing-master (who was Captain J. T. Hayes for the entire period 1905–1908), 2 mates, 6 seamen, and 2 cooks, or 11 men in all, and their subsistence, with the exception of that of the cabin cook. The Department bore all cost of alterations required to fit the vessel for her work, and furnished subsistence for the scientific personnel, consisting of the commander of the vessel, 1 surgeon, and 2 or 3 observers, together with the cabin cook. At times it was found that the vessel was undermanned to meet successfully the many and varied requirements of an ocean scientific expedition. This matter could not well be remedied, however, until the Department had a vessel of its own.

The non-magnetic ballast referred to in the charter-party consisted of stone, obtained at San Francisco, which, upon careful test, was found to be non-magnetic.

The *Galilee* proved herself a splendid sea boat, and, as already said, one of the fastest sailers of her size in the Pacific Ocean. Previous to entering our service, she had made as much as 308 miles in a day with full cargo. (See Plate 1, Fig. 2.) For our purpose, however, a day's run of 100 to 150 miles amply sufficed, representing approximately the distances apart of the magnetic stations.

By special courtesy of the Secretary of Commerce and Labor, the *Galilee* was classed as a "yacht" in order to facilitate her passages from port to port. This classification began at Honolulu, September 1905. Universal courtesy was shown her by port officials and customs officers, everything possible being done at the ports visited to facilitate her work.

Throughout the three years' operations, during which cruises were carried out all over the Pacific, but one accident befell the *Galilee*. This occurred at Yokohama in August 1906. A typhoon suddenly springing up, the vessel dragged her anchors and she was blown against the breakwater and sunk in about 14 feet of water. However, in 12 days she was ready to resume her voyage to San Diego, without serious damage to ship or to instruments.

SYNOPSES OF THE GALILEE'S CRUISES, 1905–1908.

CRUISE I, AUGUST TO DECEMBER 1905.

After the various necessary alterations (see page 130) were completed, and an inspection was made by the President of the Carnegie Institution of Washington, the *Galilee* was ready to enter upon her duties in August 1905. Magnetic observations were made under the Director's instructions and supervision, at various places on the shores around San Francisco Bay, from the results of which the most suitable place for swinging ship was determined. The *Galilee* was then swung, with the aid of a tug, on August 2, 3, and 4, in San Francisco Bay, between Goat Island and Berkeley, and the various ship's deviation coefficients were thus ascertained. (See Plate 1, Fig. 1.)

On August 5, 1905, the *Galilee* started from San Francisco on her first cruise, securing magnetic observations daily to a greater or less extent, according to conditions of the weather and sea, swinging twice under sail, and arriving at San Diego, August 12. This first short passage of the cruise was an experimental trip, various instruments and methods being subjected to trials under the supervision of the Director, who accompanied the expedition as far as San Diego for this purpose; during this trip he also completed the training of the observers, and tested under sea conditions the deflecting apparatus devised for measuring the horizontal intensity of the Earth's magnetic field.

After some further alterations had been made at San Diego and the deviation coefficients had been redetermined, the *Galilee* again set sail on September 1, this time for the Hawaiian Islands, and arrived at Honolulu on September 16. The shore observations and the instrumental comparisons at the Honolulu Magnetic Observatory having been completed, she left Honolulu September 28; after the vessel had been swung at a point abreast the Honolulu Magnetic Observatory, sail was set for Fanning Island, where the *Galilee* arrived on October 10. When the necessary harbor swings and shore observations at Fanning were completed, a course was taken south, on October 14, to about 1°.6 south latitude in longitude 197°.3 east, which point was reached on October 17; next a northwestward course was followed to about meridian 190°.5 east, thence to Honolulu, where the expedition arrived on November 7. After completion of her observations, the *Galilee* left Honolulu November 12, following a northwesterly course to about 28°.2 north latitude and longitude 196°.5 east, from which point she proceeded to a point somewhat north of latitude 41°.2 in longitude 209°.7 east, and thence she followed a direct course to San Diego. The first cruise was thus completed at San Diego on December 9, 1905, a distance of 10,571 nautical miles having been covered. The necessary swings and closing shore observations were made at San Diego between December 11 and 18.

The commander of the vessel on this cruise was J. F. Pratt, an experienced officer of the United States Coast and Geodetic Survey. By the courtesy of the Secretary of Commerce and the Superintendent of the Coast and Geodetic Survey, he was granted the necessary furlough, and entered the temporary employ of the Department of Terrestrial Magtism for the purpose of assisting the Director in the inauguration of the magnetic survey of the ocean areas, and to prepare the vessel for the purposes of the expedition. The other members of the vessel's scientific personnel were: Dr. J. Hobart Egbert,[1] magnetic observer and surgeon; J. P. Ault, magnetic observer; and P. C. Whitney,[1] magnetic observer and watch officer. The sailing-master was Capt. J. T. Hayes. For a fuller account of the cruise see J. F. Pratt's report (pp. 128–134) and abstract of log (pp. 141–143).

[1]Member of the United States Coast and Geodetic Survey, courteously granted the required furlough to enter the temporary employ of the Department of Terrestrial Magnetism.

CRUISE II, MARCH TO OCTOBER 1906.

To settle the various matters pertaining to the continuation of the work and the proposed additional alterations in the ship and in the instruments, which were shown desirable by the experience of the first cruise, the Director made an inspection trip to the *Galilee* at San Diego, December 15–18, 1905. As all the members of the scientific personnel of the first cruise, excepting Observer J. P. Ault, were obliged to return to their duties with the United States Coast and Geodetic Survey at the expiration of their furloughs, it was necessary to reorganize the staff. W. J. Peters, who had been in charge of scientific exploring parties of the United States Geological Survey in Alaska, and had been second in command and in charge of the scientific work of the second Ziegler Polar Expedition (1903–1905), was intrusted with the command of the *Galilee* for the balance of her work (1906–1908). To him were assigned as assistants on the second cruise, Observers J. P. Ault and J. C. Pearson (formerly instructor in physics at Bowdoin College), and Dr. H. E. Martyn, surgeon and recorder. Alterations in the vessel, decided on by the Director, were made chiefly under the direction of J. F. Pratt, in command of first cruise, who also rendered the new commander the requisite assistance in the preparations for the second cruise. (See Plate 1, Fig. 3.)

The alterations, harbor swings, and shore observations having been completed, the *Galilee* left San Diego on March 2, 1906, and took a direct course for Fanning Island. A stay of 10 days from March 31 to April 10 was made at this port, during which time all necessary shore and swing observations were made at the stations occupied on the first cruise. The next stop was made at Pago Pago, Samoan Islands, from April 26 to May 1. On account of great local attraction, and from lack of tug facilities, no harbor swings or shore observations were made at this point. At Apia, Samoan Islands, May 3 to 9, comparisons were made between the *Galilee* instruments and those of the German Geophysical Observatory, then in charge of Dr. Franz Linke, to whose kindness and cooperation appreciative reference is made. The Apia Geophysical Observatory was originally established under the auspices of the Göttingen "Königliche Akademie der Wissenschaften" for the purpose of participating in the scientific program of the British and German Antarctic Expeditions of 1902–03. Later it was continued, at the solicitation of the Carnegie Institution of Washington, in order to furnish magnetic data desired in connection with the magnetic survey of the Pacific Ocean. Harbor swings were not made at Apia, owing to the lack of sufficient tug facilities and to the strong harbor currents.

At the next port, Suva, Fiji Islands, comparisons were made between the instruments of the ship and those used by G. Heimbrod, then in the employ of the Department as a temporary magnetic observer for the work on the islands of the South Pacific. Harbor swings were also made at Suva on May 18 and 20. Jaluit, of the Marshall Islands, was reached on June 21 and shore and harbor observations were made, inclusive of a vessel swing, after which a course was made for Guam on June 30. Between July 11 and 24, harbor swings and shore observations were made at San Luis d'Apra, Guam. Thence sail was set for Yokohama, Japan, where the expedition arrived on August 13.

At Yokohama numerous shore observations as well as harbor swings were made and, through the courtesy of Dr. K. Nakamura, in charge of the Central Meteorological Observatory of Tokio, and of Dr. A. Tanakadate, of the University of Tokio, comparisons with the observatory standards of Japan were secured. To both of these gentlemen, and to their assistants, grateful acknowledgment should be made.

On August 24 the *Galilee* dragged her anchors in a typhoon and was blown on the breakwater at Yokohama, and sank in 14 feet of water; as soon as possible she was dry-docked and the necessary repairs were made. Fortunately the damage was not very serious, and she was enabled to take up her work again on September 6, on which date the expedition left Yokohama for San Diego. Arriving at San Diego on October 19, she had thus terminated her second cruise in the Pacific Ocean and had covered on this cruise approximately

16,286 nautical miles. The closing shore observations were next made and the vessel was swung on October 22, 1906. Throughout the cruise magnetic observations were made as frequently as the weather and sea conditions permitted. For further information see abstract of log (pp. 143–146).

CRUISE III, DECEMBER 1906 TO MAY 1908.

Between November 1 and December 22, 1906, various shore observations, harbor swings, and investigations were made at San Diego and the vessel was overhauled and outfitted preparatory to her third cruise. During November 16–22, Mr. Peters conferred with the Director at Washington, and received final instructions for the forthcoming cruise. December 22 the *Galilee* set sail from San Diego and entered upon "Cruise III," the scientific party consisting of the following persons: W. J. Peters, in command; Observers J. C. Pearson and D. C. Sowers; and Dr. G. Peterson, surgeon and recorder. Captain J. T. Hayes, as heretofore, was sailing-master. Mr. Pearson was relieved by Observer P. H. Dike at Sitka, Alaska, July 31, 1907. (See Plate 2, Figs. 1 and 2.)

The port of Nukahiva, Marquesas Islands, was reached on January 18, 1907. No harbor swing of the vessel being possible here, the *Galilee*, upon completion of the shore work, proceeded on January 24 to Tahiti, arriving there January 31. During a stay of 19 days at this port, harbor swings and land observations were carried out in detail. The next stop was made at Apia, Samoan Islands, where, between March 3 and 14, various standardizations and comparisons of instruments were made at the Apia Geophysical Observatory. This was the second time that these highly essential observations and checks on the instrumental constants of the ship had been obtained at this important observatory. The observer-in-charge, Dr. G. Angenheister, as well as the retiring observer-in-charge, Dr. F. Linke, rendered the *Galilee* all necessary assistance, hereby gratefully acknowledged. Harbor swings of the *Galilee*, however, could not be attempted at this port.

Leaving Apia March 14, Yap Island was made on April 14. Here various observations consumed 9 days. Sailing from Yap Island April 23, Shanghai was reached on May 8, where the principal stop was made. Comparisons of the *Galilee* instruments were made with the standard instruments of the Zikawei Observatory, Father J. de Moidrey, S. J., in charge of the magnetic work, furnishing every facility possible, for which our hearty thanks are due. Swings of vessel, on account of high tides and absence of motive power on the *Galilee*, could not be made here in port, but had to be undertaken directly after leaving Shanghai on May 31, in the mouth of the Yangtse River, where they were secured with great difficulty and delaying the vessel until June 4.

From Shanghai Mr. Peters was directed to proceed due east towards Midway, putting in there, if conditions did not make the entry to the harbor hazardous with a sailing vessel, and from thence to make Sitka, in order to cover this passage during as favorable a part of the year as possible. Tempestuous weather, however, was encountered on almost the entire trip, blowing the vessel out of her set course, preventing swings, and rendering impossible magnetic-declination observations because of absence of sun or stars, so that the course and program of work outlined could be followed only approximately. For about 750 nautical miles from Shanghai the course was practically the same as that of the *Challenger*, and no landing on Midway Island could be safely attempted. After following an easterly course in general to longitude 181°.5 east, latitude 37° north, course was laid directly for Sitka, the *Galilee* entering this harbor July 14, 1907, and being swung on July 16 to 19. In spite of the bad weather, the trip from Shanghai of 5,507 nautical miles was made in 41 days, averaging about 134 nautical miles per day.

The Director met the *Galilee* at Sitka on July 28, inspected the work and instrumental outfits, and discussed with the commander the future work. Two new instruments were introduced in the work, viz, the newly received and improved sea dip-circle 189, and a

almost a direct one to about 31° north latitude in 137°.5 west longitude, from which point course was set for the Golden Gate. San Francisco was reached on May 21, 1908, thus concluding Cruise III, begun at San Diego on December 22, 1906, and having a total length of about 36,977 nautical miles.

On Cruise III, 12 harbors were visited, at all of which extensive shore observations and intercomparisons of ship and land instruments were made; in 3 of the harbors swinging ship could not be undertaken, either for want of tug facilities or because of insufficient space. 20 primary land stations were established; also, in the neighborhood of the primary stations, 20 secondary stations for purposes of intercomparison and standardization of ship's instruments. While at sea during Cruise III, in addition to the course observations, which were made as frequently as weather and sea conditions permitted, frequent swings, under sail, on 6 to 8 headings, were carried out. Astronomical observations for position, with determinations of position by dead reckoning, daily intercomparisons of 5 chronometers, and daily meteorological observations were made.

The closing shore observations were made at San Francisco, and after the swing observations on May 23, 25, and 28 were completed, the *Galilee* was returned to her owners on June 5, 1908. She had been in almost continuous commission since August 1905, or a period of 3 years less 2 months, during which cruises of 63,834 nautical miles were carried out with her in all parts of the Pacific Ocean, without serious mishap, and without loss of human life. For further information regarding Cruise III, the abstract of ship's log (pp. 147–154) may be consulted. The three cruises of the *Galilee* are shown on Plate 6.

METHODS OF WORK ON THE GALILEE.

GENERAL PRINCIPLES FOLLOWED.

From the very beginning of the ocean magnetic work on the *Galilee* in 1905, two principles were steadfastly held in view:

a. To get useful work done and make the results promptly known.

b. To strive for the highest accuracy attainable in all magnetic elements.

Early in 1905 the Director spent a month abroad consulting various eminent investigators as to the requirements of ocean work, but could get practically no information in addition to what he had already obtained in his previous experience on Coast and Geodetic Survey vessels, on board of which magnetic work had been initiated under his direction in 1903. Thanks to this experience, it was possible for him, during the period of the experimental trip of the *Galilee* from San Francisco to San Diego, in August 1905, to fix upon the methods used practically throughout the three years the vessel was in commission.

The general principles followed were to secure complete control of each instrumental constant in every available manner, and to obtain independent checks upon the observed values of the magnetic elements by securing simultaneously two independent determinations of each element, under conditions as widely different as possible; *i. e.*, different observers, different instruments, and at different stations on the observing bridge, so that the corresponding ship-corrections or deviation-corrections would either vary in amount or even change sign.

The instructions called for special harbor swings when feasible, each swing to be on both helms and on a separate day. These swings generally required a tug, though a launch would do under favorable weather conditions. Swings at sea, under sail, were also prescribed at as frequent intervals as conditions of sea and weather permitted. Under sail, usually one and sometimes two out of eight equidistant headings would be missed. In order to make swings possible for a sailing vessel in calm weather, the *Galilee* was equipped on her second cruise with a naphtha launch swung at the stern davits when not in use. With the aid of

PLATE 1

1

2

3

Views of Galilee, Cruise I.

1. Swinging ship, San Francisco, August 2, 1905 2. Galilee under sail. 3. General view of Galilee.

this launch, the ship was pulled around, during a swing, or towed along, if need be, in calm weather, in order to get sufficient headway to steer. This was tried with some success on the second and third cruises when calm weather was encountered.

Regarding the magnetic observations made on the ship's course, the endeavor was to distribute the observations over varying courses as far as possible. In other words, the attempt was to vary the magnitude and sign of the deviation corrections between successive swings as much as possible under the conditions encountered.

Upon arrival at port, besides harbor swings, shore observations were made, both with the set of absolute land magnetic instruments (magnetometer, and dip circle or earth inductor) and with the ship magnetic instruments, consisting of a standard compass, a sea dip-circle, and a sea deflector described later. Wherever there was a magnetic observatory, as at Christchurch (New Zealand), Honolulu, Apia, Zikawei, Sitka, and Tokio, comparisons were made with the observatory standards. Thus sufficient opportunities were afforded for the required control of the instrumental constants.

It was soon shown that, by the methods employed, the observational errors were not only considerably less than the chart errors, but were also, in general, less than or about on the order of the errors of the deviation-corrections. In other words, the uncertainty of the deviation-correction soon became our chief concern. If this was so with the precautions taken on the *Galilee*, having, as already said (p. 7), smaller deviation-coefficients than any other vessel previously engaged in magnetic work, and swinging ship every third or fourth day, it would have been much truer on a vessel having larger deviation-coefficients and less opportunity for swings, as had been the case in previous expeditions. Obviously, then, there was no need to defer the effort to obtain useful results until ocean instruments had reached the same state of perfection as land instruments, unless one were assured that funds would soon be available for the building of a wholly non-magnetic ship. This assurance we did not have when the work was begun on the *Galilee*, and so we were determined to make the ocean work a success and to make the results known promptly. As a consequence, it was already possible in the June 1906 issue of *Terrestrial Magnetism and Atmospheric Electricity* to call attention to large systematic errors in the Pacific Ocean charts of the magnetic declination, inclination, and intensity of field. Subsequent data have been supplied with equal promptness to the leading hydrographic establishments which construct and issue magnetic charts for the use of mariners.

The prompt reduction of the observations and the many controls insisted on whenever the vessel reached port served to disclose the weak points, but not always as quickly in the early work as desired. Thus, because the deviation-coefficients were different at the various positions of the instruments, it was not possible to get an immediate comparison, for example, in declination observations made at two different stations on the ship. The deviation corrections could not be successfully determined until the completion of a cruise covering a large enough range in magnetic latitude. And here is where the great advantage of having a non-magnetic ship, like the *Carnegie*, counts most heavily; on board her it is possible to make a nearly final computation a few minutes after completing the observations, and thus to check up an observation at once and repeat it, if necessary.

The observers did not merely make the observations on board the ship, but also the first, or field, reductions. The observations and preliminary computations were not allowed to accumulate, but were forwarded promptly from the first mailing-port to the office at Washington, where they were subjected to a careful examination, and the final reduction was made as soon as possible. Abstracts of the chief results obtained were kept aboard for future guidance.

At each cable port the commander of the vessel reported his arrival and experience, and held the departure of the vessel subject to advice from the Director. Thus the ship was kept in close and effectual touch with the Director throughout, and possible improve-

ments could readily be communicated. Usually, in past expeditions, the reduction of observations has been deferred until the close of the work, when possible improvement, suggested by the results, could no longer be made. Moreover, the publication of results generally occurred so long after the observational work was completed that other expeditions were unable to profit by the experience gained on previous ones. There appears to be nothing so harmful to research as lack of promptness in the reduction of observational data and in the publication of results. Not infrequently delay in making the data available has caused the defeat of the very purpose for which the observations were undertaken.

To accomplish prompt reduction, the following principles were followed as closely as possible:

First, to have instruments, methods of observation, and methods of computation all form one harmonious whole, not to be treated as though they were independent of one another. With instruments properly constructed and carefully tested, it has been found possible to get absolute values of the magnetic elements with an accuracy sufficing for all purposes—scientific as well as practical.

Second, to adopt such observing program as would fit the purpose, the instruments, and the form of computation. A good scheme of observation takes advantage of the capabilities of an instrument in the briefest possible time and is so arranged that independent computers can get but one result, if no computation errors have been made. Observers have had impressed upon them the fact that their observations have no value until computed and, hence, that they must bear the computer in mind and consider what his task will be.

It was thus possible for the Director to be almost as closely in touch with the work as though he himself were continuously on the vessel.

One of the first lessons learned was that it is rarely, if ever, possible to have ideal conditions in ocean work. In consequence, the development of good judgment in the observer has been one of the prime requisites. Sometimes in an instant he has to be able to change his plan of observation and be content with a fair degree of accuracy, or get no observations at all.

REGARDING OBSERVATION FORMS.

As it is difficult, even for a magnetician experienced in observatory work or in magnetic surveys on land, to form an adequate conception of the problems confronting one in ocean work, there will be given later in more detail the directions followed in the observational work, as well as specimens of observations and of computations. Various practical schemes for making satisfactory ocean observations had to be devised, and a large number of printed forms were prepared for simplifying both the recording and the computing of the various kinds of observations. Comparatively few hints could be gleaned from the published reports of previous expeditions as to the best and most efficacious methods of determining ship deviations for all three magnetic elements. While considerable work had been done with regard to observations for declination deviations, comparatively little was available for guidance in obtaining correctly and accurately the dip and intensity deviations. Fortunately this troublesome part of ocean magnetic work has been eliminated on the *Carnegie*.

Suitable printed forms are a very great help not only in properly recording observations, but also in quickly calling attention to the omission of important information required by an office computer who, necessarily, is unacquainted with the circumstances under which the observations were made. A proper and suitably arranged record of observations reduces the labor of computation.

MAGNETIC INSTRUMENTS USED IN THE GALILEE WORK.

GENERAL CONSIDERATIONS.

The available space on board ship for magnetic work is necessarily restricted and in fact is never as large as one would like—not even on the *Carnegie*. Hence it becomes essential to arrange the instruments so that what is aimed at can be accomplished without bringing them so close as to have an effect on one another, thus again introducing deviation corrections. There are three elements to be determined: the magnetic declination, inclination, and intensity of the Earth's field.

The general experience in magnetic work has abundantly shown the need of getting, whenever possible, a totally independent check on each element. Hence each element should be determined twice, preferably by simultaneous observations, which would require 6 different instruments or the measurement of more than one element with the same instrument. The first is rarely practicable because of the limited space for observing and the desirability of taking advantage of the best possible conditions regarding steadiness of ship, etc.

Our developments have accordingly been along the second line, viz, that each instrument should be capable of measuring, as far as practicable, at least two different magnetic elements. Thus an instrument primarily intended for magnetic declination was arranged, by a suitable deflection device, to measure also the horizontal intensity; one arranged chiefly for horizontal intensity was so made that declination could be observed with it, and finally the adopted dip circle measured both the inclination and the total intensity. Thus it was possible to apply all needful checks, and the instrumental equipment was such that the three magnetic elements could be determined wherever the vessel might happen to be. In regions of low horizontal intensity it is better to employ a total-intensity method; hence the need of appliances for measuring both.

Next, a symmetrical development of all instruments was striven for. It was recognized as a mistake to pick out any one instrument, *e. g.*, an intensity instrument, and devote exclusive attention to it, disregarding the way it would fit in with the other appliances. Hence, from the start, equal attention was bestowed on all three elements, various methods and instruments being studied and thoroughly tried out under actual sea conditions.

The improvements in instruments and the new principles which were developed for the work of the *Carnegie* are described on pages 177–203.

SEA INSTRUMENTS FOR MAGNETIC DECLINATION.

The magnetic declination was determined on board the *Galilee* chiefly with a Ritchie United States Navy standard liquid compass and azimuth circle of latest pattern. This well-constructed compass is made by E. S. Ritchie and Sons of Brookline, Massachusetts, and in only one size, viz, 7⅜-inch card curved inward, graduated to every degree, and is provided with four cylinders of needles with central buoyancy, the keel-lines being enameled on copper. The azimuth circle is the Ritchie type III, as used in the United States Navy; it is carefully fitted to the top of the compass, and carries the optical parts. The rays of the Sun are received directly upon a cylindrical mirror and reflected through a right-angle prism on the opposite side of the ring, appearing on the card as a bar of light upon the graduation. (See Plate 3, Figs. 1–4.)

Some declination results were also obtained with a Negus liquid compass, bearing the imprint, "sold by T. S. and J. D. Negus." It was made by E. S. Ritchie and Sons, and is catalogued by them as a "flat-card compass with central buoyancy"; the card is 8 inches in diameter, is graduated to single degrees, and supports six cylinders of magnetic needles, these cylinders being somewhat smaller than those in the Ritchie standard compass. This compass is not so well constructed as the "standard," and is listed, size for size, at about half

the price of the latter. The azimuth circle is the Negus pattern, and is described in connection with the sea deflector, page 24. (See Plate 5, Figs. 1–4.)

Some experimental declination observations were also made with a Kelvin compass. This is the dry, silk-suspended card compass, designed and patented by Sir William Thomson (Lord Kelvin). The Kelvin azimuth instrument for this compass was made by the Kelvin and James White Company. (See Plate 3, Fig. 5.)

Practically every modern azimuth device was given a trial, but none was found equal to the requirements of all the varied conditions encountered. In general the simplest devices were found to be the best. With bright Sun and a fairly smooth sea, good results can be obtained by a careful observer with any of the best azimuth circles in use. For the varied conditions encountered, the observers on the *Galilee* gave preference, in general, to the Ritchie azimuth circle mentioned above, this having both a prism-reflection device for fairly bright Sun and a direct-vision method. Apparently there was considerable room here for improvement, for it frequently happened that, under conditions which still permitted securing satisfactory azimuth observations on land, none could be made at sea, because the Sun was either too high or too faint to admit of obtaining good results with the available azimuth-devices.

Every known appliance was found subject more or less to the error arising from motion of the card while the magnetic bearing of the celestial body was being taken. To eliminate this error it was necessary to extend the observations over a sufficiently long interval so that, on the average, it could be assumed that the effect of the various motions of the card had been eliminated. This had to be done more or less blindly, however, as one could never tell just at what point of the arc of motion the magnetic azimuth of the stellar body was obtained. Furthermore, all azimuth appliances had movable parts subject to wear with frequent use, such as the axes of mirrors or of prisms and the wear of the azimuth circle on the bowl. Likewise, graduation errors of the card had to be considered. The result of the defects in the usual ship's compasses and azimuth circles was the introduction of "apparent" deviation corrections, not due to the ship's magnetism, but to purely instrumental causes. To be able to separate the "apparent" from the "true" deviations, it was necessary to go through an elaborate series of shore observations whenever the vessel reached port. The ship instruments were invariably dismounted and used ashore alongside of the customary magnetic outfits for land work. *As far as known, it was in the work of the Galilee that the two sources of deviation-coefficients—those due purely to ship's magnetism and those due to defects in the magnetic instruments—were first systematically separated.* (See, for example, pp. 60–62.)

The difficulties of securing azimuth observations at sea were further increased by the meteorological conditions frequently encountered in the Pacific Ocean, viz, clouds and fog. For example, on the experimental cruise from San Francisco to San Diego in August 1905, we went out to sea 150 miles to get beyond the fog prevailing on the coast at that time of the year, and not until the fourth day out did we secure the azimuth observations necessary to give declination results.

The problem of securing the magnetic bearings of celestial objects, and hence results for magnetic declination, was the most serious one encountered in the steady progress of the magnetic survey of the Pacific Ocean. In time of cloud or fog, results for magnetic inclination and intensity could be obtained, but none for magnetic declination. Thus on some portions of the cruises of the *Galilee* there were very few opportunities to secure declinations. There may have been encountered on these portions weather that would ordinarily be characterized as fine weather for navigation, permitting the securing of sufficient sextant observations for navigating the vessel, but the observers still failed to obtain satisfactory magnetic-declination results in sufficient number, chiefly on account of the instrumental difficulties above mentioned.

Practically every difficulty in securing magnetic results at sea, with the desired degree of accuracy, has been surmounted, as will be seen from the specimen results given later, with the exception of this particular one—how to secure magnetic declinations when no celestial object is visible with the aid of which a true azimuth can be determined. On land the magnetic meridian can be referred to some fixed object, the azimuth of which may be determined at leisure and when the skies permit. At sea, in cloudy weather, no fixed object is to be had. It is hoped that some time tests may be made as to how far a device based on the gyroscope will solve this problem.

While L. A. Bauer's attention was being devoted to the perfecting of appliances and methods for inclination and intensity, W. J. Peters was making a careful study of instruments for measuring the magnetic declination at sea. Special experiments and studies were carried on by him as opportunity afforded, especially on the third and last cruise of the *Galilee*. As the result, there was devised the "marine collimating-compass," which became the principal declination-instrument on the *Carnegie*. There have been eliminated in this compass (see pp. 177–178) the chief instrumental sources of error in magnetic-declination observations at sea described on page 18.

Studies of the declination results with the instruments which were used in the *Galilee* work showed that on land the magnetic declination could be obtained with the standard Ritchie 7⅝-inch liquid compass, using either the cylindrical mirror or the dark plane mirror, within 0°.2, and with special care within 0°.1. However, these devices did not afford such precision when used at sea; it was found, for example, that the results from 8 different sets of 10 pointings each differed at times as much as 0°.5. The Kelvin azimuth attachment on the dry compass was frequently found to give even more discordant results, which, however, in some measure, may have been caused by the near synchronism of the card oscillation and the roll of the ship.

SEA INSTRUMENT FOR INCLINATION AND TOTAL INTENSITY.

The magnetic inclination and total intensity of the Earth's magnetic field were determined with the well-known "Lloyd-Creak dip-circle," modified as experience showed necessary. This form of dip circle, designated hereafter as "sea dip-circle," for use primarily in observations at sea, replaced the well-known "Fox dip-circle," devised in 1835, which had made possible the admirable ocean magnetic work in the fourth decade of the last century on the *Erebus*, *Terror*, and *Pagoda*, and had been used in subsequent expeditions (*Challenger*, 1872–76; *Gazelle*, 1874–76; and on various Arctic and Antarctic vessels).

Briefly described, the new instrument applied the method of Lloyd's needles for the purpose of determining the absolute inclination and the relative total intensity at sea; it embodied a number of modifications of the Fox dip-circle, the chief improvement being in the mounting of the needles, which greatly facilitated the various operations, reducing to a minimum the possibility of injury to pivots of needle, permitting reversal of needles, etc. The improvements were devised by Capt. Ettrick Creak before his retirement from the superintendency of the Compass Department of the British Admiralty, and the expenses of the initial experiments were defrayed by the British Admiralty. Several instruments were constructed under Captain Creak's direction, and, after having passed the tests of the Kew Observatory, were supplied to the Antarctic vessels of 1902–04, the *Discovery* of Great Britain and the *Gauss* of Germany. Unfortunately, there were some instrumental defects in these Lloyd-Creak dip-circles, the German observer (Dr. F. Bidlingmaier) being highly dissatisfied with the performance of the instrument on the *Gauss*. For some reason any intensity observations which may have been made at sea on the *Discovery* with the new instrument have not been published in the volume of results of the British expedition. An instrument supplied about the same time to the United States Coast and Geodetic Survey, and another one used on the first cruise of the *Galilee*, likewise required modification before they could be used successfully.

DESCRIPTION OF SEA DIP-CIRCLE USED ON CRUISE I.

Plate 4, Figure 1, shows the original form of L. C. dip-circle mounted on a tripod for shore observations. The counterpoise, seen attached to the base, is only used for balancing the instrument when mounted on board ship on the gimbal stand. The illustration also shows a compass attachment, added by us for shore-work, as described later.

The graduated back-circle and other parts of the Fox dip-circle are omitted in the L. C. instrument and replaced by thick ground glass. There is, therefore, only the one graduated vertical-circle for reading the inclination of the needle; it is 11.4 cm. inside diameter and is graduated every 10 minutes. At our request the recent instruments have the vertical circle numbered every 2° instead of every 5° as formerly, counting continuously from 0° to 360° instead of from 0° to 90° for each quadrant.

The needles are 11.35 cm. long and have cone-shaped axles terminating in small cylindrical ends, about 0.5 mm. long, rounded off at the extremity and highly polished. The needle, when mounted, swings in the plane of the vertical circle. The ends, or points, of the needle come very near the graduated arc and the readings are made with sufficient accuracy directly on the circle with the aid of the microscopes, there being no verniers, such as used in land instruments.

As the sea dip-circle is designed for use on board ship, the agate knife-edges of the land dip-circle are replaced here by jewel cup-bearings in which the pivots of the needle rest or turn. The jewels, fixed to the cross-bars of the circle, are highly polished sapphires in which conical cavities, slightly larger than the axles of the needles, have been drilled and polished. The upper half of the jewel is removed, thus leaving a cup into which the axles of the needle can be lowered by the lifter provided. By this arrangement the needles can be retained in place even when the gimbal stand, described below, upon which the instrument is placed, is subject to irregular motions, due to those of the ship.

Each microscope for reading the position of the needle is faced with ivory to light the circle and contains a single central thread; in making observations the microscope-thread is set on the point of the needle, whereupon the degrees and minutes (by estimation into tenths of a 10-minute space) are read directly upon the circle. It is not absolutely necessary to set the thread directly on the point of the needle, for the reading can be taken by noting the position of the point directly on the circle; in the deflection observations of the intensity determinations, however, in order to secure perpendicularity of the two needles to one another, it is essential to set the thread on the point of the suspended needle.

Holes are drilled in the weighted needle for inserting the weight in either end according to sign of the inclination. A small box of spare weights is provided.

As in the case of the Fox dip-circle, an ivory scraper is provided, to be used in rubbing and slightly tapping the vertical brass knob on the top of the instrument (below the compass attachment; see Plate 4, Fig. 1). With this ivory scraper, sufficient vibration is imparted to the pivots of the suspended needle to overcome the friction between them and the sides of the jewels, so as to cause the needle to settle down to the lowest point of the bearing.

The brass case shown at right angles to the microscopes is for the purpose of protecting the deflecting needle from injury to the pivots and from sudden changes of temperature during intensity observations.

The chief improvement of the Lloyd-Creak dip-circle over the Fox dip-circle consists, accordingly, in the construction of the needles and in the removal of the upper halves of the jewels in which the pivots of the needle work. This form of bearing permits making observations in all positions employed for securing absolute results on land, and also permits ready removal and replacing of the needle. The dip needles used in the sea work can, therefore, have their polarities reversed for elimination of error due to eccentricity of center of gravity, just as for land work.

deflections were impossible when within about 30° or 40° of the magnetic equator. In this region the total intensity of the Earth's magnetic field was too small in comparison with that exerted by the deflecting needle, and so the suspended needle would not come to rest perpendicular to the deflecting needle. Thus, on the 1905 cruise of the *Galilee*, the L. C. dip-circle became unavailable for total-intensity observations before the vessel reached Honolulu. Similar experiences were encountered in 1904 by the Coast and Geodetic Survey steamers *Bache* on a trip to Jamaica and Colon and by the *Patterson* on a trip to Honolulu. Accordingly the original deflection distance was increased from 7.3 cm. to 7.9 cm. and at the same time a second deflection distance (9.4 cm.) was introduced, making the instrument everywhere available, at least for the latter distance. It only required a change in the deflection distance from 7.3 cm. to 7.9 cm. to make it possible to use the instrument and method over the entire Pacific Ocean, instead of for the limited region above mentioned. A brass case (see Plate 4, Fig. 3) for the deflecting needle was made, so as to avoid handling the needle during a set of observations, the change from short distance to long distance being effected by a simple inversion of the case, in which the needle is mounted eccentrically.

Next, the milled heads of the footscrews were graduated and means provided for insuring that the instrument when mounted on the gimbal stand should actually be level. The heights of the footscrews were repeatedly determined and controlled for an invariable and level position of the circle whenever the vessel was in port, and from these determinations it was possible to set the instrument level at any time. We do not recall seeing described in any book on ocean magnetic work in what way the dip circle was actually set level on the gimbal stand, although the full error of level may go into the inclination. Upon one occasion the accidental setting of footscrew *B* in the place intended for footscrew *C* produced an error of about 1°.5 in the inclination. In this connection, special attention was also paid to the accurate balancing and leveling of the instrument, with the aid of counterpoise, when mounted on board ship on the gimbal stand.

From the method of observation invariably followed, four determinations of inclination were secured, two of these being with the regular dip-needles according to the absolute method, inclusive of reversal of polarity of needle, and two being "deflected dips," *i. e.*, those resulting from the deflection observations at two distances for getting total intensity, hence not involving any additional time. The scheme of observation was such that each dip applied practically to the same moment of time and to the same geographic position of ship, which of course was moving throughout the observations. In 1905 the agreement between the values of the inclination obtained from the deflection observations and from the regular dip-needles was not always satisfactory. Upon investigation it was found that this was chiefly due to the lateral play of the suspended intensity-needle, No. 3, in the jewels. In the first L. C. dip-circles, the pivots of the various needles were not always precisely of the same length; hence, in order not to have the jewels so close as to bind on the pivots of any one needle, they were put far enough apart to prevent this. It thus occurred that some lateral play resulted for the needle with the shortest distance between the ends of the pivots, which, in the case considered, happened to be intensity needle No. 3. The rubbing of the brass knob with the ivory scraper, or the motion of the ship, doubtless caused the suspended needle to move so as to change its distance from the fixed deflecting-needle (No. 4), by a fraction of a millimeter—sufficient to produce an appreciable error in the observations. To overcome this difficulty the jewels were adjusted so as to fit needle No. 3, and other needles were substituted for those that were found to bind for this position of the jewels.

For certain shore work there were also provided, for use when necessary, a compass attachment and an astronomical telescope, so as to make the sea dip-circle a universal instrument—a theodolite, dip circle, and magnetometer combined. The compass attachment served ashore for setting the plane of the dip circle in the magnetic meridian when it was not desired, or not possible, to use the magnetic-prime-vertical method, and also for

obtaining values of the magnetic declination within 2′ or 3′. The instrument is not recommended, however, for general land work, having been designed to meet the special needs of work at sea.

In addition to perfecting the instrument itself, special experiments have been in progress with the view of disclosing the cause of outstanding errors. There is no great difficulty in perfecting a magnetic instrument which shall admit of observations with the desired absolute accuracy over a limited region, but when the same accuracy must be insured over practically the entire globe, then problems present themselves not readily appreciated. Even for land instruments, as has been repeatedly found, the problem is not such a simple one. Accordingly, in our work, great stress has been laid on the necessity not to overestimate the absolute accuracy obtained, but, on the contrary, continually to assume that the desired accuracy is not being reached and, hence, that it is of the utmost importance to get independent checks in every possible manner. Thus not only has every opportunity been embraced in port to get shore intercomparisons between all ship instruments and land outfits (our own as well as those of local observatories), but there also have been devised special testing-appliances at Washington.

One peculiarity of the various sea dip-circles which have come to our notice has not yet been wholly explained, viz, well-nigh invariably the dip-needle corrections are negative on good land dip-circles, or on approved earth-inductors. This correction may be as much as 5′ and more; hence the need of the continual control spoken of in previous paragraphs. In these instruments the house in which the needle swings is of brass, whereas in land dip-circles it is of wood. Throughout our experience, covering magnetic instruments of every type and make, we have not yet found one—be it a magnetometer or a dip circle—that has proved wholly satisfactory if the magnet house is of brass. Accordingly, one of our future experiments will be to replace the metal house of the sea dip-circle with wood to see whether the rather large absolute corrections can thus be avoided.

The possibility of a better way of mounting the needle than in the present jewels is also receiving attention. Furthermore, a marine earth-inductor has been designed and installed on the *Carnegie* to serve as another means of control on the sea dip-circle. (See pp. 196–200.)

For further information regarding the sea dip-circles and best methods of observing, see the *Carnegie* work, pages 195–196, and the extracts from instructions (pp. 115–127).

SEA INSTRUMENT FOR HORIZONTAL INTENSITY.

As described in the previous section, the modifications introduced in the original sea dip-circle made it possible to obtain total intensity (F) observations in all magnetic latitudes, beginning with the second cruise of the *Galilee*. The inclination or dip (I) being observed at the same time with the same instrument, the value of the horizontal intensity (H) is obtained by computation with the aid of the formula

$$H = F \cos I$$

In accordance with our adopted principles, it was highly desirable also to obtain H directly, in regions of not too low values of H, *i. e.*, in not too high magnetic latitudes, by some convenient and independent method. Accordingly in the spring of 1905, L. A. Bauer, having in mind this desideratum and the failures experienced in low magnetic latitudes with the original sea dip-circles, undertook the devising of a special and simple deflecting apparatus, which could readily be attached, if necessary, to the ordinary navigating compasses, or form an entirely independent instrument. At that time Bidlingmaier's "double compass" had not been perfected, and even if it had, it would not have answered our requirements. The simplest possible contrivance was desired both from an instrumental as well as from a computing standpoint. For one reason or another previous appliances for measuring the horizontal intensity at sea had not proved entirely satisfactory.

DESCRIPTION OF SEA DEFLECTOR.

For the reasons above set forth there was, accordingly, developed a deflecting arrangement based on the sine-deflection formula, which implies that the deflecting magnet shall be at right angles to the deflected one when the state of equilibrium has been reached. The deflecting magnet was mounted vertically above the center of suspension of a magnet system (compass card), instead of in the same horizontal plane with it and off to one side, *e. g.*, to the east or west, as is done in most forms of land magnetometers and as was also the case in Neumayer's "deviations magnetometer," used on the *Gauss*. This new instrument is here termed the "sea deflector"; in various forms it has been used throughout the work of the *Galilee* and the *Carnegie* for determining both the magnetic declination and the horizontal intensity.

For experimental sea-deflector 1, used on the *Galilee's* cruises up to July 30, 1907, there was utilized for base of the instrument an 8-inch Ritchie-Negus liquid compass (No. 31974), the kind ordinarily employed in navigation. Next a bridge, with a disk on top for carrying the deflecting magnet, was attached at right angles to the sight line or sight bows of the latest form of Negus azimuth-circle, provided with the said liquid compass. These sight bows consisted of two stout parallel brass wires bent into bows, somewhat over a millimeter apart; they served to define the vertical sight-plane passing between them and through a brass pointer, with the aid of which the compass was read, or any point of the card set upon; they took the place of the telescope in the land magnetometer. (See Plate 5, Fig. 1.)

To make a setting with the deflecting magnet mounted on the disk, the azimuth circle was turned, carrying the deflector and sight bows, until the brass pointer was over the south end of the compass card. Then, since the magnet, by construction, was mounted at right angles to the sight line or bows, and as the latter were set directly over or parallel to the north-and-south diameter of the compass (assumed for the present to define the magnetic axis of the compass card), it followed that, in the position of equilibrium between magnet and card, the magnetic axes of the two were at right angles to each other; thus the condition of the simple sine-deflection method was secured.

Both lubber-lines, marked on the inside of the compass bowl, were then directly read on the compass card to the nearest tenth of a degree, holding the eye so as to avoid parallax. In this way one of four operations required to complete a set was carried out. Let us say, in operation *a*, the north end of the deflecting magnet was towards the east, and the setting of the brass pointer, with the aid of the bows, was made on the south point of the compass card; then, in *b*, the azimuth circle would be turned so as to make a setting on the north point of the compass card, the north end of the magnet then being to the west; next, *c*, the magnet was turned around on its support, so that north end would be east, setting, however, again on north point of compass; and finally, *d*, azimuth circle was turned and pointer set on south point of compass, north end of magnet being then west. In brief, practically the same four deflection positions usual in land magnetometers could be carried out with the sea apparatus.

The difference in the lubber-line readings for operations *a* and *b*, or *c* and *d*, or *b* and *c*, or *a* and *d*, gave twice the angle by which the compass card was deflected from the magnetic meridian owing to the presence of the deflecting magnet above it, and the mean of the two readings of any one of those pairs gave the magnetic meridian, barring errors due to eccentricity of mounting and of magnetic axes. The mean deflection-angle would be free from errors, due to these two causes. The magnetic-meridian reading of the card was also recorded before the deflecting magnet was mounted, and again after removal. The temperature of the magnet was read, and the time was recorded, both at the beginning and ending of each set of four deflection-readings.

in the ship's heading during observations, were eliminated as follows: If but one observer was available, who likewise had to record for himself, directions were given to the helmsman to hold a certain course as nearly as possible for an hour to an hour and a half, and to call out "on" when he was on the course. During this period about 8 complete sets could be made by a skillful observer, using two magnets, in all positions, embracing 32 independent settings. In general this interval of time proved sufficient to justify treating as accidental the errors due to shiftings of course, and hence of lubber-line, during settings, so that the mean of all readings yielded a satisfactory result. Or still better, if a second person was available, as was usually the case, who could record for the observer, he placed himself at the standard compass and called out when ship was on the course, whereupon the observer quickly made his setting, having previously made an approximate setting. Owing to the damping effect of the liquid in the compass, as noted above, a set of four readings, from which an approximate value of H could be derived, would be made even on board ship under trying conditions of sea, within about 8 or 10 minutes. A method more generally employed was to take simultaneous readings of the ship's head with the standard, or other spare compass, close by, and then apply the necessary corrections to the observed deflection-angles. Thus the agreement in the individual sets was improved, though the final result was practically the same as by the first method.

As is seen from the above description, the deflecting attachment was so designed that it could readily be mounted on a compass for obtaining the required horizontal-intensity observations, and readily dismounted when it was desired to make declination observations with the same compass, or to use the latter in navigating the vessel. Thus, in an instant, the same instrument used for navigation purposes, or for getting the magnetic declination, could be converted into a horizontal-intensity instrument, and the design of not multiplying instruments unduly was carried out.

Deflector 2.—When on her third cruise the *Galilee* reached Sitka, Alaska, it was possible, on July 31, 1907, to replace experimental deflector 1 by a somewhat improved instrument, No. 2. For this new deflector a standard Ritchie azimuth circle, with sighting bows added, served as framework for carrying the deflecting magnet. (See Plate 5, Figs. 2–4.) A standard Ritchie U. S. Navy liquid compass (No. 33566) took the place of the Negus compass used in deflector 1. The mounting and encasing of the deflecting magnet were also improved. Values of the horizontal intensity and magnetic declination were again obtained. No. 2 was in use during the balance of the *Galilee's* work, which closed in May 1908.

Both deflectors 1 and 2 were of the type designated A, namely, that in which the supports for the deflecting magnet were carried by a framework rotating on the compass bowl, and the deflection-angles were read directly on the card graduation. The improved type B was introduced in the *Carnegie* work. In this type of deflector the supports of the deflecting magnet form a permanent attachment to the compass bowl, the bowl itself being rotated when settings are made, and the angles being read by vernier on a graduation cut on the edge of the bowl. For the description of this type, see pages 190–194.

MOUNTING OF MAGNETIC INSTRUMENTS ON THE GALILEE.

CRUISE I, AUGUST TO DECEMBER 1905.

Figure 1, Plan A, shows the arrangement and spacing of the instruments as mounted on the observing-bridge for use during the experimental work from San Francisco to San Diego, California, August 2 to 23, 1905. (See also Plate 1, Fig. 1.) The position of the center of the sea dip-circle was unaltered throughout the three cruises of the *Galilee;* it serves, therefore, as the initial point of distance-reference for the various instruments.

Sea dip-circle 169 (*D. C. 169*), with which the magnetic inclination and the total intensity were determined, was mounted on the heavy, regular, cast-brass Dover stand with

18 inches of the foremast. This made possible the arrangement and spacing of the 4 instruments (sea dip-circle, standard Ritchie liquid compass, sea deflector, and Kelvin compass) used for Cruises II and III. (See Fig. 1, Plan *C*.) The inventory of instruments (pp. 29–32) will show what particular instrument of each type was in use during the various portions of these cruises. For view of observing-bridge, see Plate 2, Figure 1.

LAND MAGNETIC INSTRUMENTS.

At practically every port visited, as already explained on page 15, the ship magnetic instruments were compared with a magnetometer and a land dip-circle or an earth inductor. Before and after each cruise, or whenever returned to the Office, the land instruments carried by the vessel were always standardized at Washington by direct comparisons with the standards adopted for the reduction of all results to a common basis; those standards, designated as "C. I. W. Standards" (see p. 77), are the same as given in Volumes I (p. 42) and II (p. 16). In order to supplement the direct comparisons and to control any possible changes in the constants, additional checks were secured, whenever opportunity offered at ports visited, by comparisons with reserve land instruments carried by the vessel, or with instruments in use by observers of the Department of Terrestrial Magnetism engaged in other field work. The specific land and ship instruments will be found mentioned in the inventory on pages 28–32. The types of land instruments used are fully described and illustrated in Volumes I (pp. 2–11) and II (pp. 5–15); the types of ship instruments used are described and illustrated on pages 17–26.

INSTRUMENTAL OUTFIT FOR THE GALILEE WORK.

CRUISE I, AUGUST TO DECEMBER 1905.

MAGNETIC INSTRUMENTS.

I. *For magnetic declination at sea.*—(1) Ritchie liquid compass 29971, provided with azimuth circle 387–III and brass binnacle 316 for use on board ship and tripod for use on shore, all by E. S. Ritchie and Sons; (2) Negus liquid compass 31974 (manufactured by E. S. Ritchie and Sons), provided with a Negus azimuth circle and a wooden binnacle for use on board ship (the tripod for 29971 was used for shore work with 31974); (3) Kelvin dry compass (card 20, Pat. 8050) and bowl (13, Pat. 5892), provided with extra card (Pat. 15625), extra pivot and bearing, and Kelvin azimuth instrument 3619, by the Kelvin and James White Company, mounted on board ship in a wooden binnacle supplied by T. S. and J. D. Negus. The designations adopted, respectively, for the 3 compasses with their appurtenances are: R1A, D1, and K.

II. *For magnetic inclination and total intensity at sea.*—Sea dip-circle 169, with dip needles 1 and 2 and intensity needles 3 and 4, provided with brass gimbal-stand 169 for use on board ship and tripod for use on shore, all by A. W. Dover. The designation adopted for the dip circle is 169, followed by the numbers of dip needles in Roman type and of intensity needles in italicized type, thus: 169.12, 169.1*34*, 169.*34*, etc. For cases when the intensity results are from both deflection and loaded-dip observations the designation of the intensity needles is followed by a dagger (†), thus: 169.*34*†.

III. *For horizontal intensity at sea.*—Sea deflector 1, designed and constructed by the Department of Terrestrial Magnetism, consisting of special attachments and mountings for the Negus azimuth circle used on Negus liquid compass 31974 and provided with deflecting magnets 45 and NL. The designation adopted for the deflector and compass is D1.

IV. *For magnetic declination and horizontal intensity on land.*—Magnetometer 36, complete with tripod, deflection bar, and appurtenances, by T. Cooke and Sons, and supplemented with theodolite 5464 and tripod for astronomical observations on shore, all

XI. *For magnetic inclination and total intensity at sea.*—Sea dip-circle 35, loaned by the United States Coast and Geodetic Survey, with dip needles 2 and 5 (5 being from circle 163), intensity needles[1] 3 and 4, 8 of circle 163, and 4 of circle 169, provided with brass gimbal-stand 169 for use on board ship and tripod 169 for use on shore; this dip circle with its appurtenances was originally made by A. W. Dover, but prior to its assignment to the *Galilee* early in 1906, it was extensively modified and improved in the instrument shop of the United States Coast and Geodetic Survey (see pp. 21–23). The designations adopted for dip-circle 35 are: 35.2(5)*34*, 35.2(5)*3*(*8*), 35.2(5)*3*(*4*), etc. The numbers in parentheses refer to needles not belonging to dip circle 35, and the italicized numbers refer to intensity needles; for cases when both deflection and loaded-dip observations were made, the designation for the intensity needle is followed by a dagger (†), thus, 35.2(5)*3*(*4*)†.

XII. *For horizontal intensity at sea.*—Sea deflector 1 same as for Cruise I. The designation adopted for the deflector and compass is the same as before, viz, D1.

XIII. *For magnetic declination and horizontal intensity on land.*—(1) Magnetometer 36,[2] same as for Cruise I; (2) magnetometer 30, complete, with tripod, deflection bar, and appurtenances, by T. Cooke and Sons, loaned by the United States Coast and Geodetic Survey, used at one station only. The designations adopted, respectively, for the magnetometers are 36 and 30. (3) Theodolite 3578 with tripod, by C. L. Berger and Sons and loaned by W. J. Peters, was used for auxiliary observations at shore stations.

XIV. *For magnetic inclination on land.*—(1) Land dip-circle 171, provided with dip needles 1 and 2, intensity needles 3 and 4, and tripod, all by A. W. Dover, was used until May 1906; (2) land dip-circle 178, provided with dip needles 1, 2, 5, and 6, intensity-needle pairs 3 and 4, and 7 and 8, compass attachment, and tripod by A. W. Dover, used throughout the cruise. The designations adopted, respectively, for the two dip circles are 171.12, and 178.1256 (the intensity needles were not used). (3) Land dip-circle 4655 with dip needles 3 and 4 by Casella, loaned by the United States Coast and Geodetic Survey, was used at one station only; the designation adopted for this dip circle is 4655.34. (4) Sea dip-circle 35 with compass attachment was also used for shore observations (a few shore observations were made with needle 1, which was returned to the Office for repairs just before the *Galilee* sailed). (5) Sea dip-circle 169 with its needles and compass attachment as for Cruise I was also used for a few observations made prior to the sailing of the *Galilee*, after which 169 was returned to the maker for extensive alterations and remodeling in accordance with the specifications of the Department of Terrestrial Magnetism.

SEXTANTS, CHRONOMETERS, AND WATCHES.

XV. *Sextants.*—(1) No. 2611 and 2617 by Ponthus and Therrode; (2) No. 3265 by C. Plath; (3) unnumbered sextant by L. Weule.

XVI. *Chronometers and watches.*—(1) Marine chronometers 264 by A. Kittel, 1809 by T. S. and J. D. Negus and loaned by W. J. Peters, 53157 by E. Dent and Company, 53862 by E. Dent and Company, with ship and gimbal cases; (2) pocket chronometer 244 by A. Kittel for shore use; (3) deck watch 54672 by E. Dent and Company.

METEOROLOGICAL INSTRUMENTS AND MISCELLANEOUS EQUIPMENT.

XVII. *Meteorological instruments.*—Same as for Cruise I, with the addition of minimum thermometer, Fahrenheit scale, 4948 by H. J. Green.

XVIII. *Miscellaneous equipment.*—Same as for Cruise I.

---

[1]Needle 4 of 35 was broken on Feburary 16, 1906, and was replaced by needle 8 of 163; because of erratic results, this latter needle was replaced by needle 4 of 169 on August 23, 1906, and used with needle 3 of 35 for the intensity observations during the remainder of the cruise.

[2]Magnetometer 36 was slightly damaged by the accident to the *Galilee* on August 24, 1906.

and tripod 178, all by A. W. Dover; (2) land dip-circle 171 from March 9 to May 24, 1907, provided with dip needles 1 and 2, 5 of circle 172, and 6 of circle 172, intensity-needle pair 3 and 4, compass attachment, and tripod, all by A. W. Dover. The designations adopted, respectively, for the 2 dip-circles are 178.1256 and 171.12 (the intensity needles and extra dip needles were not used); (3) sea dip-circles 35, 169, and 189, with their needles and compass attachments, were used also for shore observations.

ATMOSPHERIC-ELECTRIC INSTRUMENTS.

XXIV. *Instruments for observations in atmospheric electricity beginning August 4, 1907.*—(1) Conductivity apparatus 1, complete with accessories, Gerdien's design, by Spindler and Hoyer; (2) dispersion apparatus 1394, Elster and Geitel's design by Günther and Tegetmeyer, complete with electroscope 1417, dry-pile 1408, and accessories; (3) ion counter 1455, Ebert's design, by Günther and Tegetmeyer, complete with electroscope 1443, dry-pile 1410, and accessories; (4) potential-gradient apparatus consisting of electroscope 987, Exner's design, with flame collector, Elster and Geitel's design, and accessories, by Günther and Tegetmeyer; (5) radioactivity apparatus 1432 for soil and water, Elster and Geitel's design, complete with electroscope 1416, and accessories by Günther and Tegetmeyer; (6) radioactivity apparatus for air, including electroscope 1437, dry-pile 1449, and accessories by Günther and Tegetmeyer; (7) voltmeter 4381 model 45 by the Weston Electrical Instrument Company; (8) miscellaneous equipment, including induction coil with condenser, insulators, tripod, brass gimbal stand 2, etc.

SEXTANTS, CHRONOMETERS, WATCHES, AND DIP-OF-HORIZON MEASURER.

XXV. *Sextants.*—(1) Nos. 2575, 2611, and 2617 by Ponthus and Therrode; (2) Nos. 10756 and 10759 by the Keuffel and Esser Company; (3) No. 3265 by C. Plath; (4) unnumbered sextant by L. Weule; (5) gyroscopic collimator and octant 2679 complete with accessories, by Ponthus and Therrode, from March 7, 1907.

XXVI. *Chronometers and watches.*—(1) Marine chronometers 254 by A. Kittel, 264 by A. Kittel, 1809 by T. S. and J. D. Negus, loaned by W. J. Peters, 2761 by G. E. Wilkins, 53157 by E. Dent and Company, 53862 by E. Dent and Company, with ship and gimbal cases; (2) pocket chronometers 231 by A. Kittel from March 9 to May 24, 1907, 241 by A. Kittel from September 6, 1907, 244 by A. Kittel, 253 by A. Kittel to August 7, 1907, for shore use; (3) watches 2 by the Hamilton Watch Company, 3 by the Hamilton Watch Company from March 9 to May 24, 1907, and deck watch 54672 by E. Dent and Company.

XXVII. *Dip-of-horizon measurer.*—Dip measurer 4048, model A, by Carl Zeiss, from March 11, 1907.

METEOROLOGICAL INSTRUMENTS AND MISCELLANEOUS EQUIPMENT.

XXVIII. *Meteorological instruments.*—Same as for Cruises I and II, with the addition of the following: (1) Marine mercury barometer 3948, English scale, by H. J. Green; (2) Marvin sling psychrometer, centigrade scale, thermometers 8186 and 8189 by H. J. Green (broken during cruise); (3) thermograph 39804 by Richard Frères, to August 2, 1907; (4) thermograph 40418 was returned for repairs on July 30, 1907, and was replaced by thermograph 46032 by Richard Frères on August 31, 1907; (5) 6-inch thermometers, centigrade scale, 4823, 8828, 8835, 8837, 8840, all by H. J. Green.

XXIX. *Miscellaneous equipment.*—Same as for Cruises I and II, with the addition of the following: (1) Artificial horizon, by L. Weule; (2) three-arm protractor 10031, by the Keuffel and Esser Company; (3) stereoscopic glasses, by Ponthus and Therrode; (4) special non-magnetic wall tents, 9 feet by 9 feet, for shore work.

GENERAL PROPERTY AND SUPPLIES.

Besides the instrumental equipment listed on pages 28–32, the general property and supplies aboard the *Galilee*, 1905–1908, were about as follows:

I. Navigation charts, maps, and atlases of various kinds.
II. Library of books on astronomy, navigation, mathematics, magnetism (general and terrestrial), general physics, atmospheric electricity, general chemistry, meteorology, geography, geology, biology, sailing ships (sails and sail-making, etc.), encyclopedias, dictionaries, and general literature.
III. Medical books and supplies.
IV. Miscellaneous appurtenances.

SPECIMENS OF OBSERVATIONS AND OF COMPUTATIONS.

Reference has already been made, page 16, to the various forms devised for recording and computing the observations made aboard the *Galilee*. The specimens given in this section will serve to show the utility of these forms, and at the same time help to make clear the methods of observation and of computation. The specimens are confined to ship work. Those illustrating land work will be found in Volume I, pages 30–41.

MAGNETIC OBSERVATIONS DURING SWING OF VESSEL.

First are given specimens of magnetic observations obtained during one of the *Galilee's* last swings at San Francisco, May 25, 1908. The swing was made with the aid of the tug *Liberty*, which came alongside about 4^h 30^m a. m. and towed the *Galilee* to the north of Goat Island, in about 10 to 27 feet of water, practically in the same place where the swings were made when the vessel set out on her work in August 1905. The position was verified from time to time by sextant angles to prominent objects. The swing was on 8 equidistant headings, both helms, first port and then starboard, the tug towing ahead with about 60 fathoms of line out. Conditions of sea and weather were good throughout.

A swing (both helms) had been made two days previously (May 23) and another was made on May 28. On May 23 the tug did not come alongside the vessel until 7 a. m., so that by the time the swings were made the trigonometric conditions were not favorable for observations of the magnetic declination. Also it was discovered that sea dip-circle 189 had been out of level during the first half of the swing on that day. Accordingly, a third swing was made on May 28, the tug coming alongside at sunrise. The specimen inclination observations (p. 44) are taken from the swing of May 28, 1908. The swing on May 25 began with port helm, heading west, and was, accordingly, made in the order: W, NW, N, NE, E, SE, S, SW. The vessel was next swung with starboard helm as follows: E, NE, N, NW, W, SW, S, SE.

DECLINATION OBSERVATIONS, SAN FRANCISCO BAY, MAY 25, 1908.

Page 34 contains the magnetic-declination observations (Form 21) made aboard the *Galilee* in San Francisco Bay on May 25, 1908, a. m., during the first half of the port-helm swing, using the standard Ritchie compass R3C (see p. 31) and employing first the prism method and, next, the alidade method.

The details are sufficiently clear from the headings and adjacent designations to require no further explanation. It will be seen that on each heading there were 5 settings made on the Sun, using the prism, next 5 settings, using the alidade; the average time for 5 settings was about 25 seconds, the 10 settings requiring about 1 minute. Whether the prism or alidade was used first depended somewhat upon the brightness of Sun.

On page 35 is found a specimen "Computation of Ocean Declination Observations" (Form 22). Before entering on Form 22, the data from Form 21, instrumental corrections,

dependent on card-graduation errors and Sun's altitude, are applied to the mean settings, both for prism and alidade, as explained on page 62. Thus for heading west, the mean observed setting by prism is N 50°.26 E; the value after applying the instrumental correction (+0°.33) is N 50°.59 E. Similarly, the mean observed setting by alidade is N 50°.68 E; the corrected setting is N 50°.79 E. Accordingly, the mean corrected setting for prism and alidade is, N 50°.69 E, which is finally the quantity entered on Form 22, opposite the mean local apparent time: $\frac{1}{2}(2^h\,12^m14^s.6 + 2^h\,12^m\,48^s0) + 3^h\,16^m\,20^s = 5^h\,28^m\,51^s$. In this way are filled out the columns: "Local Apparent Time," and "Sun by Compass."

Magnetic Observations on Swing: Declination (D)

(Form 21)

Station: San Francisco Bay
Date: May 25, 1908, A. M.
Compass: Ritchie 29499 (R3C)
Weather: b
Sea: S

Lat: 37° 51′ N
Vessel: Galilee
Obs'r: W. J. P.
Wind: 0
Roll: 0°

Long: 122° 23′ W
Com'd'r: W. J. P.
Rec'd'r: D. C. S.
Temp: 13° C.
Helm: Port

Ship's Head	Prism Method		Alidade Method		Remarks
	Time by Chron. 241	Sun by St. Comp.	Time by Chron. 241	Sun by St. Comp.	
	h m s	°	h m s	°	
W	2 12 05	N 50.3 E	2 12 36	N 51.0 E	*Magnetic articles removed:* Yes
	11	50.2	44	50.5	Ship swung by: Tug
	15	50.3	49	50.5	
	18	50.2	53	50.6	
	24	50.3	58	50.8	
Means	2 12 14.6	N 50.26 E	2 12 48.0	N 50.68 E	
NW	2 20 43	N 51.5 E	2 21 32	N 51.8 E	
	59	52.0	37	52.0	
	21 06	52.0	43	52.2	
	17	51.7	47	52.2	
	21	51.7	51	52.2	
Means	2 21 05.2	N 51.78 E	2 21 42.0	N 52.08 E	
N	2 27 46	N 52.7 E	2 28 14	N 53.2 E	
	50	52.8	22	53.0	
	54	52.8	40	53.4	
	57	52.9	46	53.3	
	28 00	52.9	50	53.2	
Means	2 27 53.4	N 52.82 E	2 28 34.4	N 53.22 E	
NE	2 38 57	N 54.0 E	2 37 18	N 54.8 E	
	39 03	54.2	38 10	54.3	
	04	54.6	15	54.2	
	18	54.6	33	54.5	
	24	54.5	45	54.3	
Means	2 39 09.2	N 54.38 E	2 38 12.2	N 54.42 E	

CHRONOMETER COMPARISONS

	Before	After
	h m s	h m s
Chron. D53157	13 23 30	16 18 20
Corr'n on G. M. T.	− 17 21	− 17 21
G. M. T.	13 06 09	16 00 59
E.	+ 03 18	+ 03 18
G. A. T.	13 09 27	16 04 17
Long.	8 09 32	8 09 32
L. A. T.	4 59 55	7 54 45
Chron. 241	1 43 35	4 38 26
241 on L. A. T.	+ 3 16 20	+ 3 16 19
Mean	+ 3 16 20	

Knowing the latitude of the place of observation and the local apparent time, the entries in the next column, "Sun's Azimuth," are computed with the aid of a conveniently arranged abstract from published azimuth tables, *e. g.*, those of the United States Hydrographic Office.

The observed magnetic declination, entered in the fifth column, is obtained by subtracting the Sun's magnetic azimuth ("Sun by Compass") from the true or computed azimuth. The + sign means that the magnetic declination is east of north. The values in this column are affected by the ship's magnetism, the correction of which varies from heading to heading. The mean value of the 8 equidistant headings, + 17°.96, is free from the

Analysis of Declination Deviations

(Form 23)

Station: San Francisco Bay	*Lat:* 37° 51′ N	*Long:* 122° 23′ W
Date: May 25, 1908, A. M.	*Vessel:* Galilee	*Com'd'r:* W. J. P.
Compass: Ritchie 29499 (R3C)	*Obs'r:* W. J. P.	*Comp'r:* J. P. A.
Method: Prism and Alidade	*Wind:* 0	*Reviser:* H. W. F.
Sea: S *Weather:* b	*Roll:* 0°	*Helm:* Both

Ship's Head	I. Observed Deviation[1]			III. Computation of Deviation[1] and of Probable Error						
	Port	Starb.	Mean	$B_d \sin \zeta$	$C_d \cos \zeta$	$D_d \sin 2\zeta$	$E_d \cos 2\zeta$	Comp'd Dev'n[1]	v $(O-C)$	v^2
	°	°	°	°	°	°	°	°	°	
N	−.22	−.26	−.24	.00	−.22	.00	+.02	−.20	−.04	.0016
NE	−.12	−.14	−.13	−.13	−.16	+.14	.00	−.15	+.02	04
E	−.20	−.22	−.21	−.19	.00	.00	−.02	−.21	.00	00
SE	−.20	−.09	−.14	−.13	+.16	−.14	.00	−.11	−.03	09
S	+.26	+.22	+.24	.00	+.22	.00	+.02	+.24	.00	00
SW	+.48	+.42	+.45	+.13	+.16	+.14	.00	+.43	+.02	04
W	+.08	+.15	+.12	+.19	.00	.00	−.02	+.17	−.05	25
NW	−.10	−.11	−.10	+.13	−.16	−.14	.00	−.17	+.07	49
Sums	−.02	−.03	−.01	.00	.00	.00	.00	.00	−.01	.0107

II. Computation of Deviation-Coefficients

No.	(1) Head	(2) Dev'n[1]	(3) Head	(4) Dev'n[1]	(5) (2)+(4)	(6) (2)−(4)	Comp'n B_d (7)	Comp'n B_d (6)×(7)	Comp'n C_d (8)	Comp'n C_d (6)×(8)
		°		°	°	°				°
a	N	−.24	S	+.24	.00	−.48	0.000	.00	1.000	−.48
b	NE	−.13	SW	+.45	+.32	−.58	0.707	−.41	0.707	−.41
c	E	−.21	W	+.12	−.09	−.33	1.000	−.33	0.000	.00
d	SE	−.14	NW	−.10	−.24	−.04	0.707	−.03	−.707	+.03
							$4B_d$	−.77	$4C_d$	−.86
							B_d	−.19	C_d	−.22

Operation	(9) From (5)	Comp'n D_d (10)	Comp'n D_d (9)x(10)	Comp'n E_d (11)	Comp'n E_d (9)x(11)				
	°		°		°				
a−c	+.09	0.000	.00	1.000	+.09	$4D_d$	+.56	$4E_d$	+.09
b−d	+.56	1.000	+.56	0.000	.00	D_d	+.14	E_d	+.02

FORMULÆ

Deviation $- A_d =$ Deviation[1] $= B_d \sin \zeta + C_d \cos \zeta + D_d \sin 2\zeta + E_d \cos 2\zeta$

Probable error of Deviation[1] of single heading, $r = \pm 0.6745\sqrt{\frac{\Sigma v^2}{n-4}}$

In case of 8 headings $n=8$; hence $r = \pm 0.337\sqrt{\Sigma v^2} = \pm 0{,}^{\circ}03$

[1]Without A_d.

HORIZONTAL-INTENSITY OBSERVATIONS, SAN FRANCISCO BAY, MAY 25, 1908.

Form 24, page 37, gives a specimen set of horizontal-intensity observations made with sea deflector 2 (D2), during the swing in San Francisco Bay, May 25, 1908. On the port-helm swing, deflecting magnet 45, short deflecting-distance, was used, whereas on the starboard-helm swing, deflecting magnet 2L, short deflecting-distance, was used. To show the method, it will suffice to give the observations made on the first half of the port-helm swing, headings W, NW, N, NE. The headings of the columns and the adjacent designations will, in general, give the requisite explanations.

The first column contains the magnetic course or ship's heading, as shown by the standard compass. In the second and third columns are entered, respectively, the time and

temperature at the beginning and at the end of the set of readings on that heading. The following 5 columns give number of magnet, deflecting distance used, which letter, *A* or *B*, on case containing deflecting magnet is turned towards observer (O), whether prism is south or north, and finally whether north end of magnet is east or west. Then follows the column

Magnetic Observations on Swing: Horizontal Intensity (*H*)

(Form 24)

Station: San Francisco Bay	*Lat:* 37° 51′ N	*Long:* 122° 23′ W
Date: May 25, 1908, A. M.	*Vessel:* Galilee	*Com'd'r:* W. J. P.
Instrument: Sea Defl'r 2 (D2)	*Obs'r:* D. C. S.	*Rec'd'r:* W. J. P.
Weather: b	*Wind:* 0	*Temp:* 13° C.
Sea: S	*Roll:* 0°	*Helm:* Port

Course by St. Comp.	Time by 241	Temp. C.	Magnet	Distance	Letters	Prism	N. End Magnet	Lubber-Line Reads	Means 2 *u*	Course by Defl. C.
	h *m*	°						°	°	°
W	2 13	14.7	45	S	BO	S	E	N 70.1 W	......	....
	......	......	......	......	......	......	....	S 70.2 E	109.85	....
	......	......	......	......	......	N	W	S 69.8 W	......	....
	17	13.7	......	......	......	......	....	N 70.0 E	69.90	S 89.88 W
Means	2 15	14.2	......	......	......	......	....	2 *u*	39.95	....
NW	2 22	12.6	45	S	BO	S	W	N 65.3 W	......	....
	......	......	......	......	......	......	....	S 65.0 E	65.15	....
	......	......	......	......	......	N	E	N 25.6 W	......	....
	25	12.5	......	......	......	......	....	S 25.3 E	25.45	N 45.30 W
Means	2 24	12.6	......	......	......	......	....	2 *u*	39.70	....
N	2 29	12.2	45	S	BO	S	E	N 19.4 E	......	....
	......	......	......	......	......	......	....	S 19.5 W	19.45	....
	......	......	......	......	......	N	W	N 20.1 W	......	....
	32	12.1	......	......	......	......	....	S 19.8 E	19.95	N 0.25 W
Means	2 30	12.2	......	......	......	......	....	2 *u*	39.40	....
NE	2 34	12.7	45	S	BO	S	W	N 24.5 E	......	....
	......	......	......	......	......	......	....	S 25.0 W	24.75	....
	......	......	......	......	......	N	E	N 64.2 E	......	....
	36	12.6	......	......	......	......	....	S 64.5 W	64.35	N 44.55 E
Means	2 35	12.6	......	......	......	......	....	2 *u*	39.60	....

Remarks		*h*	*m*	*s*
Magnetic articles removed: Yes	Chronometer D53157	13	23	30
Swung by: Tug	Correction on G. M. T.	−	17	21
	G. M. T.	13	06	09
	Longitude	8	09	32
	L. M. T.	4	56	37
	Chronometer 241	1	43	35
	Chron. 241 on L. M. T.	+ 3	13	02

"Lubber-line reads," which gives the two readings of the forward and aft lubber-lines on the deflected compass-card, for each of two positions (for example, heading west: prism south, north end of magnet east; prism north, north end of magnet west). The means of the two opposite readings, for each position of prism and magnet, are formed next, counting continuously from south (0°) through west to north. The difference of the two means, *e.g.*, heading west, 109°.85 − 69°.90 = 39°.95 is *twice* the deflection angle, hence, 2*u*. The mean value of the two means, *e. g.*, heading west, S 89°.88 W, is entered in the last column, and gives the ship's heading or course by the deflector compass.

The procedure is similar for each heading, the positions of prism and north end of deflecting magnet being readily followed by the letters in the respective columns.

Form 25, page 38, contains first an abstract of the results derived from the preceding form (No. 24). The values of the single deflection-angle, *u*, expressed in degrees and hun-

dredths, are entered for each heading, and the value of the horizontal intensity, H, computed by the formula: $H = mC/\sin u$. The values of log sin u may be conveniently looked up in a table in which the argument is given to degrees and hundredths, such as Bremiker's five-place table. The values of log mC_t, corresponding to the observed mean temperature on any heading, are derived as explained in the section giving instrumental constants (p. 64). The mean value of H from the 8 equidistant headings is 0.2520 C. G. S.; the corresponding value derived from the surrounding shore observations, for the same time, is 0.2524; hence, the value of A_h in the deviation formula (p. 39) is -0.0004.

Computation of Horizontal-Intensity Observations (Swing)

(Form 25)

Station: San Francisco Bay
Date: May 25, 1908, A. M.
Instrument: Sea Defl'r 2 (D2)
Weather: b *Temp:* 13° C.
Sea: S

Lat: 37° 51′ N
Vessel: Galilee
Obs'r: D. C. S.
Wind: 0
Roll: 0°

Long: 122° 23′ W
Com'd'r: W. J. P.
Comp'r: D. C. S.
Reviser: W. J. P.
Helm: Port

Ship's Head	L.M.T.	t = Temp. C.	Magnet	Distance	Letters	Deflection Angle u	Log sin u	Log mC	Log H	Obs'd H	Deviation (without A_h) Obs'd	Deviation (without A_h) Comp'd	Corr'd H
	h m	°				°				c. g. s.	c. g. s.	c. g. s.	c. g. s.
N	5 43	12.2	45	S	BO	19.70	9.5278	8.9324	9.4046	.2539	+.0019	+.0012	.2531
NE	5 48	12.6	......	......	.....	.80	299	323	.4024	.2526	+ 6	− 2	32
E	5 59	12.0	......	......	.....	.92	324	324	.4000	.2512	− 8	− 9	25
SE	6 25	12.8	......	......	.....	.85	309	322	.4013	.2519	− 1	+ 6	17
S	6 31	14.2	......	......	.....	.78	294	320	.4026	.2527	+ 7	+ 12	19
SW	6 38	15.4	......	......	.....	.85	309	317	.4008	.2517	− 3	− 6	27
W	5 28	14.2	......	......	.....	.98	336	320	.3984	.2503	− 17	− 15	22
NW	5 37	12.6	......	......	.....	.85	309	323	.4014	.2520	0	+ 2	22
Means	6 01	13.2	......	......	.....	......	......	......	......	.2520	.0000	.0000	.2524

	c. g. s.
Horizontal intensity from ship observations....	0.2520
Horizontal intensity from shore observations...	0.2524
Hence, value of A_h........................	−0.0004

Formula: $H = mC/\sin u$

Subtracting the mean value, 0.2520, from the individual H-values, the observed deviations (without A_h) are next derived. These quantities are then analyzed on Form 23*a* (Analysis of Horizontal-Intensity Deviations, page 39) in a manner precisely similar to that followed in the analysis of declination deviations, page 36. The unit used on this form is the fourth decimal C. G. S. The resulting deviation-coefficients in C. G. S. units are: $B_h = +0.0000$; $C_h = +0.0003$; $D_h = +0.0012$; $E_h = -0.0004$. With the aid of these the computed deviations (without A_h) are obtained in upper right-hand portion of the form, and also entered on Form 25.

The computed deviations with A^h, are applied in Form 25, with signs reversed, to the observed values of H, and thus the final or corrected values of H, with deviation corrections applied, are derived. It will be seen that while the deviated or observed values of H vary from 0.2503 to 0.2539, hence show a range of 0.0036, the undeviated or corrected values exhibit a range of but 0.0015. This range might have been still further reduced had the analysis of horizontal-intensity deviations been made separately for *each* magnet, instead of for the two magnets (45 and 2L) together. The purpose, here, is merely to illustrate the method of observation and of computation. These results must be regarded as satisfactory, especially when the time consumed in the observations is considered, viz, 2 to 4 minutes for a single value of H, and about an hour for the mean value. It is to be noted that these results were obtained under ideal conditions. Later we shall have examples of observations made under severer conditions.

Analysis of Horizontal-Intensity Deviations

(Form 23a)

Station: San Francisco Bay
Date: May 25, 1908, A. M.
Instrument: Sea Defl'r 2 (D2)
Magnets: 45 and 2L
Sea: S *Weather:* b

Lat: 37° 51′ N
Vessel: Galilee
Obs'r: D. C. S.
Wind: 0 *Temp:* 14° C.
Roll: 0°

Long: 122° 23′ W
Com'd'r: W. J. P.
Comp'r: D. C. S.
Reviser: J. P. A.
Helm: Both

Ship's Head	I. Observed Deviation[1]			III. Computation of Deviation[1] and of Probable Error						
	Port, Mag. 45	Starb., Mag. 2L	Mean	$C_h \sin \zeta$	$B_h \cos \zeta$	$E_h \sin 2\zeta$	$D_h \cos 2\zeta$	Comp'd Dev'n[1]	v $(O-C)$	v^2
N	+19	+ 4	+12	0	0	0	+12	+12	0	0
NE	+ 6	− 9	− 2	+2	0	−4	0	− 2	0	0
E	− 8	− 7	− 8	+3	0	0	−12	− 9	+1	1
SE	− 1	+14	+ 6	+2	0	+4	0	+ 6	0	0
S	+ 7	+14	+10	0	0	0	+12	+12	−2	4
SW	− 3	− 2	− 2	−2	0	−4	0	− 6	+4	16
W	−17	−19	−18	−3	0	0	−12	−15	−3	9
NW	0	+ 8	+ 4	−2	0	+4	0	+ 2	+2	4
Sums	+ 3	+ 3	+ 2	......	......	......	......	......	+2	34

II. Computation of Deviation-Coefficients

No.	(1) Head	(2) Dev'n[1]	(3) Head	(4) Dev'n[1]	(5) (2)+(4)	(6) (2)−(4)	Comp'n C_h (7)	Comp'n C_h (6)×(7)	Comp'n B_h (8)	Comp'n B_h (6)×(8)
a	N	+12	S	+10	+22	+ 2	0.000	0	1.000	+ 2
b	NE	− 2	SW	− 2	− 4	0	0.707	0	0.707	0
c	E	− 8	W	−18	−26	+10	1.000	+10	0.000	0
d	SE	+ 6	NW	+ 4	+10	+ 2	0.707	+ 1	−.707	− 1
							$4\,C_h$	+11	$4\,B_h$	+ 1
							C_h	+ 3	B_h	0

Operation	(9) From (5)	Comp'n E_h (10)	Comp'n E_h (9)x(10)	Comp'n D_h (11)	Comp'n D_h (9)x(11)				
a−c	+48	0.000	0	1.000	+48	$4\,E_h$	−14	$4\,D_h$	+48
b−d	−14	1.000	−14	0.000	0	E_h	− 4	D_h	+12

FORMULÆ

$$\text{Deviation} - A_h = \text{Deviation}^1 = C_h \sin \zeta + B_h \cos \zeta + E_h \sin 2\zeta + D_h \cos 2\zeta$$

Probable error of Deviation[1] of single heading, $r = \pm 0.6745 \sqrt{\frac{\Sigma v^2}{n-4}}$

In case of 8 headings $n = 8$; hence $r = \pm 0.337 \sqrt{\Sigma v^2} = \pm 2$

[1]Without A_h and expressed in units of the fourth decimal c. g. s.

TOTAL-INTENSITY OBSERVATIONS, SAN FRANCISCO BAY, MAY 25, 1908.

Form 12*a*, page 40, gives specimen total-intensity observations with sea dip-circle 189 by the deflection method, made on headings N and NE during the port-helm swing in San Francisco Bay, May 25, 1908. The intensity needles used were Nos. 3 and 4. The form is doubtless self-explanatory, the method of observation being, in general, the same as for land work. (See Volume I, pp. 17, 18, 24, 29, 30, 39.) Here, however, the readings on the ends of the suspended needle are recorded not to minutes of arc, but to the nearest half or quarter degree. It will be observed that 4 readings are made on each end of the suspended needle, for each position of circle and needle. All operations are carried out on

each heading, the 32 readings taking, on the average, 3 to 5 minutes. The time and temperature are recorded, in the lower part of the form, at the beginning and ending of the observations on each heading.

Magnetic Observations on Swing: Total Intensity (F)

(Form 12a)

Station: San Francisco Bay
Date: May 25, 1908, A. M.
Dip Circle: No. 189

Chronometer H. W.
Needle: No. 3 suspended; No. 4 deflecting
Distance: Long

Obs'r: P. H. D.
Rec'd'r: G. P.

End of suspended needle marked *A* north. Ship's Head: N.

Circle East				Circle West			
Needle Face East				Needle Face West			
Micro. Direct		Micro. Reversed		Micro. Reversed		Micro. Direct	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
217.0	37.0	265.0	85.5	272.0	92.5	320.5	141.0
18.5	39.0	68.5	88.0	74.0	94.0	23.0	42.5
16.0	37.5	65.0	85.0	72.0	92.5	20.0	41.0
20.5	38.5	68.0	87.5	75.0	93.5	22.5	42.0
218.0	38.0	266.6	86.5	273.3	93.1	321.5	141.6
°		°		°		°	
38.00		86.55		86.80		38.45	
+62.28		24.28		24.18		+62.62	

Mean *I*: + 62°45 u_1: 24°23

End of suspended needle marked *A* north. Ship's Head: NE.

Circle East				Circle West			
Needle Face East				Needle Face West			
Micro. Direct		Micro. Reversed		Micro. Reversed		Micro. Direct	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
217.5	37.5	266.5	86.5	271.5	92.0	320.5	141.0
20.0	39.5	67.5	88.0	74.0	94.0	21.5	42.0
18.0	37.5	66.0	86.0	71.5	92.0	20.0	39.0
20.0	40.0	68.5	88.0	74.0	94.0	22.0	42.5
218.9	38.6	267.1	87.1	272.8	93.0	321.0	141.1
°		°		°		°	
38.75		87.10		87.10		38.95	
+62.93		24.18		24.08		+63.03	

Mean *I*: + 62°98 u_1: 24°13

Ship's Head	N		NE		Remarks	
	h m	*C*	*h m*	*C*		
Chron. time and temp., beginning	1 49	12°5	1 56	13°6	*Helm*	Port
Chron. time and temp., ending...	1 53	13.0	1 59	13.3	*Weather*	b
					Sea	S
Mean chron. time and mean temp.	1 51	12.8	1 58	13.4	*Wind*	0
Chron. corr. on L. M. T.	+3 53	......	+3 53		*Roll*	0°
Local mean time	5 44	......	5 51			
Mag'c mer. for circle east reads	179° 15′		134° 15′			

Form 11*a*, below, reproduces specimen total-intensity observations with sea dip-circle 189 by the loaded-dip method, made on the headings NE and N, during the starboard-helm swing in San Francisco Bay on May 25, 1908. It will be noted that the loaded needle No. 4 was used, with weight 11, which was inserted in the south end of the needle. As in the case of Form 12*a*, the headings of columns will suffice to explain the method of observation, the needle readings again being recorded to the nearest half or quarter degree, or occasionally to nearest tenth degree.

Magnetic Observations on Swing: Total Intensity (F)

(Form 11*a*)

Station: San Francisco Bay *Chronometer* H. W. *Obs'r:* P. H. D.
Date: May 25, 1908, A. M. *Needle:* No. 4 loaded; weight 11 *Rec'd'r:* G. P.
Dip Circle: No. 189

End of needle marked *A* north down. Ship's Head NE.							
Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
223.0	43.5	316.0	136.0	316.0	136.0	222.5	43.0
24.5	44.5	17.0	37.0	17.5	7.0	25.0	44.5
23.5	43.5	16.0	35.5	16.0	6.0	23.0	43.0
24.5	45.0	17.5	38.0	17.5	7.0	24.5	44.5
223.9	44.1	316.6	136.6	316.8	136.5	223.8	43.8
+44°.00		+43°.40		+43°.35		+43°.80	
+43°.70				+43°.58			
Mean *I'*: +43°.64							

End of needle marked *A* north down. Ship's Head: N.							
Circle East		Circle West		Circle West		Circle East	
Needle Face West		Needle Face East		Needle Face West		Needle Face East	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
223.0	43.5	317.0	136.0	316.0	135.0	223.0	43.0
24.5	44.0	18.0	38.0	17.0	37.5	24.5	44.5
23.0	43.0	16.0	35.5	16.5	35.0	22.5	43.0
24.0	44.5	17.0	38.0	18.0	38.0	24.5	45.0
223.6	43.8	317.0	136.9	316.9	136.4	223.6	43.9
+43°.70		+43°.05		+43°.35		+43°.75	
+43°.38				+43°.55			
Mean *I'*: +43°.47							

Ship's Head	NE		N		Remarks	
	h m	*C*	*h m*	*C*		
Chron. time and temp., beginning	3 01	16°.5	3 08	15°.0	*Helm*	Stb'd
Chron. time and temp., ending	04	15.7	14	17.0	*Weather*	b
					Sea	S
Mean chron. time and mean temp.	3 02	16.1	3 11	16.0	*Wind*	0
Chron. corr. on L. M. T.	+3 53	......	+3 53		*Roll*	0°
Local mean time	6 55		7 04			
Mag'c mer. for circle east reads	134° 15'		179° 15'			

Form 25*a*, below, shows specimen computations of horizontal intensity (H) from the total-intensity observations, made with sea dip-circle 189 during the swing at San Francisco on May 25, 1908. The upper half, marked I, gives the computation of H, based on the

Computation of Horizontal Intensity from Total-Intensity Observations, San Francisco, May 25, 1908

(Form 25*a*)

I. From deflection observations on port-helm swing

Formula: $H = C_d \cos I \csc u_1$

Heading	N	NE	E	SE	S	SW	W	NW	Mean
L. M. T.	5h 44m	5h 51m	5h 58m	6h 25m	6h 32m	6h 38m	5h 30m	5h 37m	6h 02m
Temp. (C.)	12°.8	13°.4	13°.6	14°.0	14°.8	16°.6	12°.3	12°.2	13°.7
u_1	24°.23	24°.13	23°.86	23°.97	24°.06	23°.92	23°.89	24°.12	....
I (corr'd)	62.37	62.90	63.03	62.73	61.92	61.75	61.72	61.95	....
Log. csc u_1	0.3868	0.3885	0.3931	0.3912	0.3897	0.3920	0.3926	0.3886	....
Log. cos I	9.6663	9.6585	9.6566	9.6610	9.6728	9.6752	9.6756	9.6723	....
Log. C_d	9.3405	9.3404	9.3404	9.3403	9.3402	9.3398	9.3406	9.3406	....
Log. H	9.3936	9.3874	9.3901	9.3925	9.4027	9.4070	9.4088	9.4015	....
Obs'd H	0.2475	0.2440	0.2455	0.2469	0.2527	0.2553	0.2563	0.2521	0.2500
Obs'd Dev.	−.0025	−.0060	−.0045	−.0031	+.0027	+.0053	+.0063	+.0021	....
Comp'd Dev.	−.0028	−.0057	−.0052	−.0023	+.0020	+.0057	+.0060	+.0023	....
Corr'd H	0.2527	0.2521	0.2531	0.2516	0.2531	0.2520	0.2527	0.2522	0.2524

Horizontal Intensity from ship observations... 0.2500
Horizontal Intensity from shore observations.. 0.2524
Hence, value of A'_h .... −0.0024

II. From loaded-dip observations on starboard-helm swing

Formula: $H = C_l \cos I \cos I' \csc u$

Heading	N	NE	E	SE	S	SW	W	NW	Mean
L. M. T.	7h 04m	6h 55m	6h 44m	7h 43m	7h 35m	7h 28m	7h 20m	7h 13m	7h 15m
Temp. (C.)	16°.0	16°.1	17°.2	16°.5	16°.2	17°.1	18°.4	17°.8	16°.9
I (corr'd)	62°.37	62°.90	63°.03	62°.73	61°.92	61°.75	61°.72	61°.95	....
I'	43.47	43.64	43.45	43.02	42.72	42.88	43.02	43.39	....
$u = I - I'$	18.90	19.26	19.58	19.71	19.20	18.87	18.70	18.56	....
Log. cos I	9.6663	9.6585	9.6566	9.6610	9.6728	9.6752	9.6756	9.6723	....
Log. cos I'	9.8608	9.8596	9.8609	9.8640	9.8661	9.8650	9.8640	9.8614	....
Log. csc u	0.4896	0.4817	0.4748	0.4720	0.4830	0.4902	0.4940	0.4971	....
Log. C_l	9.3846	9.3846	9.3848	9.3847	9.3846	9.3848	9.3850	9.3849	....
Log. H	9.4013	9.3844	9.3771	9.3817	9.4065	9.4152	9.4186	9.4157	....
Obs'd H	0.2519	0.2423	0.2383	0.2408	0.2550	0.2601	0.2622	0.2604	0.2514
Obs'd Dev.	+.0005	−.0091	−.0131	−.0106	+.0036	+.0087	+.0108	+.0090	....
Comp'd Dev.	+.0011	−.0090	−.0142	−.0088	+.0021	+.0096	+.0110	+.0082	....
Corr'd H	0.2518	0.2523	0.2535	0.2506	0.2539	0.2515	0.2522	0.2532	0.2524

Horizontal Intensity from ship observations... 0.2514
Horizontal Intensity from shore observations.. 0.2524
Hence, value of A''_h .... −0.0010

deflection observations, of which specimens for two headings (N, NE) are presented by Form 12*a*, page 40. In the formula, I is the inclination resulting from deflection observations on the corresponding heading with all corrections to standard applied, which, for all headings, amount to −0°.08 (see p. 69). For example, turning to Form 12*a*, the mean I,

Analyzing these by means of Form 23*a* on page 39, the following deviation-coefficients are derived: $B_i = +0°.18$; $C_i = +0°.67$; $D_i = -0°.11$; $E_i = -0°.01$. The probable error of the deviation of a single heading is $\pm 0°.05$ or $\pm 3'$.

Magnetic Observations on Swing: Inclination (I)

(Form 10a)

Station: San Francisco Bay	*Chron.:* H. W.	*Obs'r:* P. H. D.
Date: May 28, 1908, A. M.	*Needle No:* 5	*Rec'd'r:* G. P.
Dip Circle: 189		

End of needle marked *A* north. Micro. *A* on *A*. Ship's Head: N.

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
242.0	62.0	297.0	117.0	296.8	116.2	241.5	61.5
42.5	62.8	98.8	18.0	99.5	17.7	42.0	62.8
41.5	62.0	96.5	17.0	96.5	16.2	41.2	61.5
43.0	62.7	98.5	18.2	98.0	18.3	42.5	62.2
242.3	62.4	297.7	117.6	297.7	117.1	241.8	62.0
+62°.35		+62°.35		+62°.60		+61°.90	
+62°.35				+62°.25			
Mean: +62°.30							

End of needle marked *A* north. Micro. *A* on *A*. Ship's Head: NE.

Circle East		Circle West		Circle West		Circle East	
Needle Face West		Needle Face East		Needle Face West		Needle Face East	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
242.0	62.0	297.2	116.8	296.5	117.0	242.0	62.2
42.7	62.5	98.0	17.7	98.0	18.2	43.0	63.3
41.8	62.0	97.0	17.0	96.8	17.2	41.8	62.5
43.0	62.8	98.0	17.8	98.7	18.3	42.5	62.2
242.4	62.3	297.6	117.3	297.5	117.7	242.3	62.6
+62°.35		+62°.55		+62°.40		+62°.45	
+62°.45				+62°.42			
Mean: +62°.44							

Ship's Head	N	NE	Remarks	
	h m	h m		
Chron. time of beginning	5 15	5 21	*Helm*	Port
Chron. time of ending	19	24	*Weather*	b
			Sea	S
Mean chronometer time	5 17	5 22	*Wind*	0
Chron. correction on L. M. T.	+3 42	+3 42	*Roll*	0°
Local mean time	8 59	9 04		
Mag. mer. for circle east reads	179° 15′	134° 15′		

The mean value of the inclination from the ship observations is $+62°.30$, the corresponding value at the same time from the shore being $+62°.10$; hence $A_i = +0°.20$. Applying the computed deviations and A_i, with signs reversed, to the observed inclinations, the corrected values in the fifth and tenth columns result. The observed inclinations varied from 61°.72 to 63°.03, hence through a range of 1°.31, whereas the corrected values show a range of but 0°.16, or 10′.

TABLE 1.—*Summary of Deviation-Coefficients of the Galilee, San Francisco Bay, May 23, 25, and 28, 1908.*

No.	Date	Coefficients and Probable Errors						Instrument	Headings	Obs'r	Bridge Position	Remarks
	1908	A_d	B_d	C_d	D_d	E_d	P. E.					
	May 23	+0°.01	−0°.18	−0°.18	+0°.05	−0°.06	±0°.04	R3C	8p 8s	WJP	Stand. Comp.	Sun obs'd with stand. comp. by prism and alidade; both helms
	25	0.00	−0.19	−0.22	+0.14	+0.02	±0.03	R3C	8p 8s	WJP		
	28	−0.01	−0.14	−0.15	+0.15	+0.06	±0.02	R3C	8p 8s	WJP		
I	Mean	0.00	−0.17	−0.18	+0.11	+0.01	±0.03					
II	May 28	+0.04	+0.19	−0.08	+0.15	−0.03	±0.04	D2	8p 0s	DCS	Defl'r	Sun obs'd with defl'r comp. by prism and alidade; port helm
		A_i	B_i	C_i	D_i	E_i	P. E.					
	May 23	+0°.19	+0°.43	+0°.64	−0°.08	+0°.01	±0°.02	169.1A, *78*	8p 8s	DCS	Dip Circle	Reg. dip on port helm, needle 1; defl'd dip, long dist., on starb. helm
	25	+0.20	+0.18	+0.67	−0.11	−0.01	±0.05	189.*34*	8p 0s	PHD		Defl'd dip, long distance, on port helm
	28	+0.23	+0.08	−0.10	−0.14	−0.02	±0.04	189.5A, *34*	8p 8s	PHD		Reg. dip on port helm, needle 5; defl'd dip, long dist., on starb. helm
III	Mean	+0.21	+0.23	+0.40	−0.11	−0.01	±0.04					
		A'_h	B'_h	C'_h	D'_h	E'_h	P. E.					
	May 23	− 4	−38	−60	+15	− 1	± 6	169.*78*	0p 8s	DCS	Dip Circle	D. C. 169 defl'ns, long dist., starb. helm
	25	−24	−24	−56	− 4	0	± 5	189.*34*	8p 0s	PHD		D. C. 189 defl'ns, long dist., port helm
	28	−21	− 1	+15	+13	+ 3	± 5	189.*34*	0p 8s	PHD		D. C. 189 defl'ns, long dist., starb. helm
IV	Mean	−16	−21	−34	+ 8	+ 1	± 5					
		A''_h	B''_h	C''_h	D''_h	E''_h	P. E.					
IVa	May 25	−10	− 5	−126	+16	+ 3	±10	189.*4*	0p 8s	PHD	Dip Circle	D. C. 189 loaded dips, starb. helm
		A_h	B_h	C_h	D_h	E_h	P. E.					
	May 23	− 7	− 4	+11	+16	+ 1	± 3	D2.45, 2L	8p 8s	PHD	Defl'r	Defl'r obs'ns, short dist.; mag. 2L, port helm; mag. 45, starb. helm
	25	− 6	0	+ 3	+12	− 4	± 2	D2.45, 2L	8p 8s	DCS		Defl'r obs'ns, short dist; mag. 45, port helm; mag. 2L, starb. helm.
	28	+ 2	− 2	+10	+ 9	+ 2	± 4	D2.45, 2L	8p 8s	DCS		Defl'r obs'ns, short dist.; mag. 2L, port helm; mag. 45, starb. helm
V	Mean	− 4	− 2	+ 8	+12	0	± 3					

MAGNETIC OBSERVATIONS MADE ON COURSE.

The following observations will serve as specimens of a typical day's work at sea. To show what is possible under not the very best conditions, the day selected is April 14, 1908, on the passage of the *Galilee* from Callao, Peru, to San Francisco. On this day the observing conditions were as follows: roll of vessel for a. m. declination observations, 10° to 20°, hence 30° from side to side; roll of vessel for p. m. declination observations, 5° to 15°, hence 20° from side to side; roll of vessel, during observations of magnetic inclination and intensity, from side to side 30°; weather, *bc* (clear, blue sky, clouds); sea, *M* (moderate sea, or swell); wind, SE and having a force of 3–4 (Beaufort scale); temperature, 26° C.

Complete astronomical and magnetic observations were made on this day, of which specimens of the latter follow.

DECLINATION OBSERVATIONS, APRIL 14, 1908.

I. Magnetic Observations on Course: Declination (D)

(Form 21)

Station: At Sea	*Lat:* 6° 01′ S	*Long:* 98° 30′ W	*Weather:* bc	*Temp:* 26° C.
Date: Apr. 14, 1908, A. M.	*Vessel:* Galilee	*Com'd'r:* W. J. P.	*Sea:* M	*Roll:* 10° to 20°
Compass: Ritchie 29499 (R3C)	*Obs'r:* W. J. P.	*Rec'd'r:* P. H. D.	*Wind:* SE, 3–4	

Course by St. Comp.	Prism Method		Alidade Method		Remarks
	Time by Chron. 241	Sun by St. Comp.	Time by Chron. 241	Sun by St. Comp.	
	h m s	°	h m s	°	
WSW (Set 1)	1 14 59	N 71.0 E	1 16 55	N 71.5 E	*Magnetic articles removed:* Yes. Sunrise; altitude less than 6°; mast interferes
	15 05	71.5	17 09	71.8	
	21	71.0	17	71.0	
	31	70.0	22	74.0	
	45	71.8	27	73.5	
	56	71.0	33	72.0	
	16 05	70.0	38	71.0	
	13	70.8	42	71.5	
	24	70.8	47	70.6	
	31	70.0	52	72.5	
Means	1 15 47	N 70.79 E	1 17 28	N 71.94 E	
WSW (Set 2)	1 27 48	N 72.0 E	1 26 15	N 71.0 E	
	55	71.0	21	70.5	
	28 00	71.2	27	70.8	
	06	72.0	32	69.5	
	13	70.0	39	70.0	
	22	70.8	53	71.0	
	49	70.0	58	71.2	
	54	70.0	27 02	72.0	
	29 02	71.0	10	71.4	
	08	70.8	14	72.0	
Means	1 28 26	N 70.88 E	1 26 45	N 70.94 E	

CHRONOMETER COMPARISONS

	Before	After
	h m s	h m s
Chron. 53157	12 54 00	13 20 30
Corr'n on G.M.T.	− 15 30	− 15 30
G. M. T.	12 38 30	13 05 00
E.	− 0 20	− 0 20
G. A. T.	12 38 10	13 04 40
Long.	6 34 00	6 34 00
L. A. T.	6 04 10	6 30 40
Chron. 241	1 07 41	1 34 11
241 on L. A. T.	+4 56 29	+4 56 29
Mean	+4 56 29	

II. Magnetic Observations on Course: Declination (D)

(Form 21)

Station: At Sea	*Lat:* 6° 01′ S	*Long:* 98° 30′ W	*Weather:* bc	*Temp:* 26° C.
Date: Apr. 14, 1908, A. M.	*Vessel:* Galilee	*Com'd'r:* W. J. P.	*Sea:* M	*Roll:* 10° to 20°
Compass: Ritchie 33566 (D2).	*Obs'r:* P. H. D.	*Rec'd'r:* W. J. P.	*Wind:* SE, 3–4	

Course by St. Comp.	Prism Method		Alidade Method		Remarks
	Time by Chron. 241	Sun by St. Comp.	Time by Chron. 241	Sun by St. Comp.	
	h m s	°	h m s	°	
WSW (Set 1)	1 19 16	N 71.8 E	1 21 33	N 70.5 E	*Magnetic articles removed:* Yes. Sunrise; altitude from 3° to 5°
	40	72.0	38	70.0	
	50	72.0	44	72.0	
	58	71.5	55	69.7	
	20 05	72.0	22 00	70.0	
	10	72.0	10	70.8	
	17	72.0	16	71.0	
	22	71.5	22	71.0	
	33	71.8	32	71.0	
	43	72.0	23 00	71.0	
Means	1 20 05	N 71.86 E	1 22 07	N 70.70 E	
WSW (Set 2)	1 25 08	N 72.2 E	1 23 28	N 71.0 E	
	13	73.2	33	69.8	
	22	71.0	39	71.2	
	26	71.2	48	71.0	
	31	71.6	56	72.0	
	38	72.0	24 08	72.5	
	43	72.0	19	72.0	
	48	71.5	29	72.0	
	54	71.7	40	71.8	
	58	71.6	47	71.7	
Means	1 25 34	N 71.80 E	1 24 05	N 71.50 E	

CHRONOMETER COMPARISONS

	Before	After
	h m s	h m s
Chron.53157	12 54 00	13 20 30
Corr'n on G.M.T.	− 15 30	− 15 30
G. M. T.	12 38 30	13 05 00
E.	− 0 20	− 0 20
G. A. T.	12 38 10	13 04 40
Long.	6 34 00	6 34 00
L. A. T.	6 04 10	6 30 40
Chron. 241	1 07 41	1 34 11
241 on L. A. T.	+4 56 29	+4 56 29
Mean	+4 56 29	

DECLINATION OBSERVATIONS, APRIL 14, 1908—*Continued.*

III. Magnetic Observations on Course: Declination (D)

(Form 21)

Station: At Sea	*Lat:* 5° 41′ S	*Long:* 99° 55′ W	*Weather:* bc	*Temp:* 26° C.
Date: Apr. 14, 1908, P. M.	*Vessel:* Galilee	*Com'd'r:* W. J. P.	*Sea:* M	*Roll:* 5° to 15°
Compass: Ritchie 29499 (R3C)	*Obs'r:* W. J. P.	*Rec'd'r:* D. C. S.	*Wind:* SE, 3–4	*Heel:* 3° to starboard

Course by St. Comp.	Prism Method: Time by Chron. 241	Prism Method: Sun by St. Comp.	Alidade Method: Time by Chron. 241	Alidade Method: Sun by St. Comp.
	h m s	°	*h m s*	°
WSW (Set 1)	11 52 36	N 88.0 W	11 54 10	N 87.6 W
	47	87.3	13	87.7
	54	87.5	15	88.0
	59	87.0	55 38	87.0
	53 02	86.8	58	87.8
	07	87.5	56 34	86.5
	11	87.3	40	87.5
	13	87.5	44	87.3
	32	87.0	52	87.3
	46	87.5	57 08	87.0
Means	11 53 07	N 87.34 W	11 55 49	N 87.37 W
WSW (Set 2)	12 12 47	N 88.2 W	12 09 38	N 87.8 W
	50	88.0	42	87.5
	53	88.0	43	87.8
	58	88.2	10 02	87.8
	13 01	88.6	50	89.0
	13	88.6	11 14	88.5
	15	88.7	27	88.0
	21	87.5	40	87.3
	26	87.5	59	88.2
	32	88.0	12 07	87.8
Means	12 13 08	N 88.13 W	12 10 50	N 87.97 W

Remarks

Magnetic articles removed: Yes
Approx. Alt. Sun's center, by sextant:

	(Prism)	(Alidade)
For set 1	17°.7	17°.0
For set 2	12°.2	13°.4

Rigging interferes

CHRONOMETER COMPARISONS

	Before	After
	h m s	*h m s*
Chron. 53157	22 56 00	0 41 30
Corr'nonG.M.T.	− 15 30	− 15 30
G. M. T.	22 40 30	0 26 00
E.	− 0 13	− 0 13
G. A. T.	22 40 17	0 25 47
Long.	6 39 40	6 39 40
L. A. T.	16 00 37	17 46 07
Chron. 241	11 09 44	12 55 14
241 on L. A. T.	+4 50 53	+4 50 53
Mean	+4 50 53	

IV. Magnetic Observations on Course: Declination (D)

(Form 21)

Station: At Sea	*Lat:* 5° 41′ S	*Long:* 99° 55′ W	*Weather:* b	*Temp:* 26° C.
Date: Apr. 14, 1908, P. M.	*Vessel:* Galilee	*Com'd'r:* W. J. P.	*Sea:* M	*Roll:* 5° to 15°
Compass: Ritchie 33566 (D 2)	*Obs'r:* D. C. S.	*Rec'd'r:* W. J. P.	*Wind:* SE, 3–4	

Course by St. Comp.	Prism Method: Time by Chron. 241	Prism Method: Sun by St. Comp.	Alidade Method: Time by Chron. 241	Alidade Method: Sun by St. Comp.
	h m s	°	*h m s*	°
WSW (Set 1)	11 57 56	N 86.3 W	11 59 57	N 87.3 W
	58 04	86.5	12 00 06	87.5
	12	87.0	16	87.3
	20	87.2	24	87.3
	27	87.0	33	87.6
	32	86.8	43	86.8
	39	86.8	48	87.7
	59 00	87.2	12 01 00	87.8
	01	87.0	06	87.8
	06	86.5	15	87.2
			29	87.5
Means	11 58 32	N 86.83 W	12 00 42	N 87.44 W
WSW (Set 2)	12 07 40	N 87.5 W	12 05 22	N 88.7 W
	46	88.0	32	87.5
	51	87.0	44	88.0
	08 04	87.0	54	87.3
	17	87.2	06 13	87.5
	21	87.3	23	87.5
	30	87.5	31	88.5
	39	87.0	44	88.0
	46	87.5	51	88.0
	53	86.8	59	87.8
Means	12 08 17	N 87.28 W	12 06 13	N 87.88 W

Remarks

Magnetic articles removed: Yes
Approx. Alt. Sun's center, by sextant:

	(Prism)	(Alidade)
For set 1	16°.4	16°.0
For set 2	14°.1	14°.6

CHRONOMETER COMPARISONS

	Before	After
	h m s	*h m s*
Chron. 53157	22 56 00	0 41 30
Corr'nonG.M.T.	− 15 30	− 15 30
G. M. T.	22 40 30	0 26 00
E.	− 0 13	− 0 13
G. A. T.	22 40 17	0 25 47
Long.	6 39 40	6 39 40
L. A. T.	16 00 37	17 46 07
Chron. 241	11 09 44	12 55 14
241 on L. A. T.	+4 50 53	+4 50 53
Mean	+4 50 53	

HORIZONTAL-INTENSITY OBSERVATIONS, APRIL 14, 1908.

V. Magnetic Observations on Course: Horizontal Intensity (H)

(Form 24)

Station: At Sea
Date: Apr. 14, 1908, P. M.
Instrument: Sea Defl'r 2 (D2)
Weather: bc
Sea: M

Lat: 5° 41′ S
Vessel: Galilee
Obs'r: D. C. S.
Wind: SE, 4
Roll: 10° to 20°

Long: 99° 55′ W
Com'd'r: W. J. P.
Rec'd'r: W. J. P.
Temp: 26° C.

Course by St. Comp.	Time by 241	Temp. C.	Magnet	Distance	Letters	Prism	N. End Magnet	Lubber-Line reads	Means 2u	Course[1] by Defl. Comp.
	h m	°						°	°	°
W	11 16	26.4	2L	S	BO	S	E	N 79.4 W		
(Set 1)								S 79.3 E	100.70	N 89.6 E
						N	W	S 78.7 W		
								N 78.4 E	78.48	
						N	E	N 79.2 W		
								S 79.3 E		
						S	W	S 78.5 W		
	24	26.3						N 78.3 E		
Means	11 20	26.4						2 u	22.22	S 89.59 W
W	11 25	26.3	2L	S	AO	S	W	S 78.4 W		
(Set 2)								N 78.3 E	78.35	S 89.3 W
						N	E	N 79.2 W		
								S 79.4 E	100.68	
						N	W	S 78.2 W		
								N 78.5 E		
						S	E	N 79.3 W		
	30	26.2						S 79.4 E		
Means	11 28	26.2						2 u	22.33	S 89.52W
W (Set 3)	11 34	26.2	2L	S	BO			2 u	22.27	S 89.48W
W (Set 4)	11 42	26.2	2L	S	AO			2 u	22.30	S 89.47W
	h m	°						°	°	°
W	12 17	27.8	45	S	BO	S	E	N 75.4 W		
(Set 1a)								S 75.3 E	104.65	N 89.5 E
						N	W	S 74.7 W		
								N 74.7 E	74.60	
						N	E	N 75.3 W		
								S 75.4 E		
						S	W	S 74.5 W		
	24	26.5						N 74.5 E		
Means	12 20	27.2						2 u	30.05	S 89.62W
W	12 25	26.3	45	S	AO	S	W	S 74.5 W		
(Set 2a)								N 74.6 E	74.45	S 89.7W
						N	E	N 75.5 W		
								S 75.3 E	104.55	
						N	W	S 74.4 W		
								N 74.3 E		
						S	E	N 75.4 W		
	33	26.0						S 75.6 E		
Means	12 29	26.2						2 u	30.10	S 89.50W
W (Set 3a)	12 36	26.0	45	S	BO			2 u	30.05	S 89.52W
W (Set 4a)	12 43	26.0	45	S	AO			2 u	30.00	S 89.50W

Remarks

Magnetic articles removed: Yes
In shade of sails

	h	m	s
Chronometer D53157	22	56	00
Correction on G. M. T.	−	15	30
G. M. T.	22	40	30
Longitude	6	39	40
L. M. T.	16	00	50
Chronometer 241	11	09	44
Chronometer 241 on L. M. T.	+ 4	51	06

[1]Lubber-line reading of D2 when standard compass (R3C) reads on course.

TOTAL-INTENSITY OBSERVATIONS, APRIL 14, 1908.

VI. Magnetic Observations on Course: Total Intensity (F) by Loaded-Dip Method

(Form 11)

Station: At sea	*Lat:* 5° 41′ S	*Long:* 99° 55′ W
Date: Apr. 14, 1908, P. M.	*Vessel:* Galilee	*Obs'r:* P. H. D
Dip Circle: 189	*Chron:* H. W.	*Needle:* 4; weight, 11.

End of needle marked *A* north up — I

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
142.5	321.5	36.5	216.0	35.5	217.0	140.0	322.5
145.0	324.0	37.5	218.5	38.5	218.5	144.0	323.5
142.0	323.5	36.5	216.5	37.0	216.0	141.5	320.5
145.0	325.0	38.5	218.5	38.0	218.0	144.5	324.0
143.6	323.5	37.2	217.4	37.2	217.4	142.5	322.6
−36°.45		−37°.30		−37°.30		−37°.45	
	−36°.88				−37°.38		

Mean *I′*: −37°.13

End of needle marked *A* north up — II

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
142.5	320.5	36.5	216.0	35.0	216.0	142.0	322.0
145.0	324.5	39.0	218.0	38.0	218.5	145.5	324.0
140.5	321.5	35.5	217.0	36.0	216.0	142.5	321.0
145.0	325.0	38.0	218.0	38.0	217.0	144.5	324.0
143.2	322.9	37.2	217.2	36.8	216.9	143.6	322.8
−36°.95		−37°.20		−36°.85		−36°.80	
	−37°.08				−36°.82		

Mean *I′*: −36°.95

Set	I			II			Remarks
	h	m	C	h	m	C	
Chron. time and temp., beginning	10	56	26°.8	11	54	26°.6	Ship's head: West
Chron. time and temp., ending	10	59	27.0	11	57	26.5	Weather: bc Sea: M Wind: SE, 4 Roll: 10° to 30°
Mean chron. time and mean temp.	10	58	26.9	11	56	26.6	*Magnetic articles removed:* Yes
Chron. corr. on L. M. T.	+5	26		+5	26		
Local mean time	16	24		17	22		
Mag'c mer. for circle east reads	300° 15′			300° 15′			

TOTAL-INTENSITY OBSERVATIONS, APRIL 14, 1908—*Continued.*

VII. *Magnetic Observations on Course: Total Intensity (F) by Deflection Method*

(Form 12)

Station: At sea	*Lat:* 5° 41′ S	*Long:* 99° 55′ W
Date: Apr. 14, 1908, P. M.	*Vessel:* Galilee	*Obs'r:* P. H. D.
Dip Circle: 189	*Chron:* H. W.	*Needles:* 3 and 4; *distance*, long

End of suspended needle 3 marked *A* north				I			
Circle East				Circle West			
Needle Face East				Needle Face West			
Micro. Direct		Micro. Reversed		Micro. Reversed		Micro. Direct	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
137.5	315.5	221.0	40.0	40.5	221.5	316.5	137.5
139.5	318.5	223.0	43.0	43.0	225.0	320.5	141.0
136.0	316.5	220.0	39.0	41.5	221.0	318.5	137.5
139.0	321.5	223.0	44.0	43.0	223.0	320.0	139.5
138.0	318.0	221.8	41.5	42.0	222.6	318.9	138.9
318°00		41°65		222°30		138°90	
359.82		41.82		41.70		180.60	
−.18						−.60	
Mean *I*: −0°39				u_1: 41°76			

Suspended needle 3 turned face about on bearings				II			
Circle West				Circle East			
Needle Face East				Needle Face West			
Micro. Direct		Micro. Reversed		Micro. Reversed		Micro. Direct	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
317.0	136.5	40.5	220.0	220.0	39.0	135.0	316.5
321.5	139.0	45.0	224.0	224.5	44.0	141.0	318.5
317.5	137.0	40.5	219.5	220.0	40.0	136.5	316.5
319.0	139.0	42.5	224.0	224.5	42.5	139.5	319.0
318.8	137.9	42.1	221.9	222.2	41.4	138.0	317.6
138°35		222°00		41°80		317°80	
180.17		41.82		42.00		359.80	
−.17						−.20	
Mean *I*: −0°18				u_1: 41°91			

Set	I and II			Remarks
	h	*m*	*C*	
Chron. time and temp., beginning	11	01	27°0	Ship's head: West
Chron. time and temp., ending	11	11	26.8	Weather: bc
				Sea: M
Mean chron. time and mean temp.	11	06	26.9	Wind: SE, 4
Chron. corr. on L. M. T.	+5	26		Roll: 10° to 20°
Local mean time	16	32		*Magnetic articles removed:* Yes
Magnetic meridian for circle east reads	269° 15′			

TOTAL-INTENSITY OBSERVATIONS, APRIL 14, 1908—*Concluded.*

VIII. *Magnetic Observations on Course: Total Intensity (F) by Deflection Method*

(Form 12)

Station: At Sea | *Lat:* 5° 41′ S | *Long:* 99° 55′ W
Date: Apr. 14, 1908, P. M. | *Vessel:* Galilee | *Obs'r:* P. H. D.
Dip Circle: 189 | *Chron:* H. W. | *Needles:* 3 and 4; *distance,* short

End of suspended needle 3 marked *A* north				I			
Circle East				Circle West			
Needle Face East				Needle Face West			
Micro. Direct		Micro. Reversed		Micro. Reversed		Micro. Direct	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
108.0	288.0	248.5	67.5	68.0	247.5	288.0	108.5
114.0	294.0	250.5	72.5	70.5	251.0	293.0	112.5
108.5	289.0	248.0	68.5	68.5	248.0	289.0	109.5
110.5	293.5	252.0	71.0	72.0	250.0	292.0	111.0
110.2	291.1	249.8	69.9	69.8	249.1	290.5	110.4
290°.65		69°.85		249°.45		110°.45	
360.25		69.60		69.50		179.95	
+.25						+.05	
Mean *I*: +0°.15				u_1 : 69°.55			

Suspended needle 3 turned face about on bearings				II			
Circle West				Circle East			
Needle Face East				Needle Face West			
Micro. Direct		Micro. Reversed		Micro. Reversed		Micro. Direct	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
289.0	109.5	68.0	248.5	246.5	67.0	109.5	290.0
292.0	112.0	71.5	253.0	250.0	70.0	114.0	293.0
290.0	109.0	67.0	249.5	248.0	66.5	110.0	290.5
291.0	112.5	70.5	252.0	249.5	70.5	115.0	291.5
290.5	110.8	69.2	250.8	248.5	68.5	112.1	291.2
110°.65		250°.00		68°.50		291°.65	
180.32		69.68		68.42		360.08	
−.32						+.08	
Mean *I*: −0°.12				u_1 : 69°.05			

Set	I and II			Remarks
	h	*m*	*C*	
Chron. time and temp., beginning	11	44	28°.0	Ship's head: West
Chron. time and temp., ending	11	52	26.7	Weather: bc
				Sea: M
Mean chron. time and mean temp.	11	48	27.4	Wind: SE, 4
Chron. corr. on L. M. T.	+ 5	26		Roll: 10° to °20
Local mean time	17	14		*Magnetic articles removed:* Yes
Magnetic meridian for circle east reads	269° 15′			

INCLINATION OBSERVATIONS, APRIL 14, 1908.

IX. Magnetic Observations on Course: Inclination (I)

(Form 10)

Station: At Sea	*Lat:* 5° 41′ S	*Long:* 99° 55′ W
Date: Apr. 14, 1908, P. M.	*Vessel:* Galilee	*Obs'r:* P. H. D.
Dip Circle: 189	*Chron:* H. W.	*Needle:* 5

End of needle marked *A* north up. Micro. *A* on *A*.

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
178.0	358.0	359.5	180.0	358.0	180.5	178.0	359.5
181.5	361.0	362.0	181.5	361.0	181.0	180.0	361.0
178.0	357.5	359.0	178.0	360.0	179.5	178.5	358.5
181.0	361.5	362.5	181.0	362.0	182.5	181.0	361.5
179.6	359.5	360.8	180.1	360.2	180.9	179.4	360.1
−0°.45		−0°.45		−0°.55		−0°.25	
−0°.45				−0°.40			
Mean: −0°.42							

Polarity reversed.[1] End of needle marked *B* north up. Micro. *A* on *A*.

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
178.5	359.0	358.5	178.5	359.5	178.0	179.0	357.5
180.5	363.0	360.5	181.5	361.0	182.0	182.0	361.5
178.0	358.5	359.0	180.0	358.0	179.0	178.5	358.5
182.0	360.5	361.5	181.0	361.0	182.5	181.0	361.5
179.8	360.2	359.9	180.2	359.9	180.4	180.1	359.8
0°.00		−0°.05		−0°.15		−0°.05	
−0°.02				−0°.10			
Mean: −0°.06							
Mean *I*: —0.24							

Polarity	*A*	*B*	Remarks
	h *m*	*h* *m*	
Chron. time of beginning	10 44	12 07	Ship's head: West
Chron. time of ending	48	11	Weather: bc
			Sea: M
Mean chronometer time	10 46	12 09	Wind: SE, 4
Chron. correction on L. M. T.	+ 5 26	+ 5 26	Roll: 10° to 20°
Local mean time	16 12	17 35	*Magnetic articles removed:* Yes
Mean L. M. T.	16ʰ 54ᵐ		
Magnetic meridian for circle east reads	269° 15′		

[1]Polarity reversed by 10 strokes of bar magnets on each face of needle.

INCLINATION OBSERVATIONS, APRIL 14, 1908—*Concluded.*

X. *Magnetic Observations on Course: Inclination (I)*

(Form 10)

Station: At Sea	*Latitude:* 5° 41′ S	*Longitude:* 99° 55′ W
Date: Apr. 14, 1908, P. M.	*Vessel:* Galilee	*Observer:* P. H. D.
Dip Circle: 189	*Chronometer:* H. W.	*Needle:* 6

End of needle marked *A* north up — Micro. *A* on *A*

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
178.0	357.0	361.0	180.0	359.0	179.5	178.0	358.0
181.0	360.5	361.5	181.5	361.5	182.5	180.5	360.5
178.5	357.0	359.0	179.0	360.0	179.5	178.5	358.0
181.0	360.0	362.0	181.5	363.0	183.0	180.0	361.0
179.6	358.6	360.9	180.5	360.9	181.1	179.2	359.4
−0°.90		−0°.70		−1°.00		−0°.70	
−0°.80				−0°.85			

Mean: −0°.82

Polarity reversed[1] — End of needle marked *B* north up — Micro. *A* on *A*

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
178.5	358.5	358.0	178.0	359.0	178.5	178.5	359.0
181.5	361.0	362.5	182.5	362.5	183.0	180.5	361.5
178.0	359.0	359.0	180.0	359.0	179.5	178.0	357.5
181.0	361.5	361.0	181.5	362.5	182.0	181.0	362.5
179.8	360.0	360.1	180.5	360.8	180.8	179.5	360.1
−0°.10		−0°.30		−0°.80		−0°.20	
−0°.20				−0°.50			

Mean: −0°.35
Mean *I*: −0.58

Polarity	*A*	*B*	Remarks
	h m	h m	
Chron. time of beginning	10 49	12 00	Ship's head: West
Chron. time of ending	54	06	Weather: bc
			Sea: M
Mean chronometer time	10 52	12 03	Wind: SE, 4
Chron. correction on L. M. T.	+ 5 26	+5 26	Roll: 10° to 20°
Local mean time	16 18	17 29	*Magnetic articles removed:* Yes
Mean L. M. T.	16ʰ 54ᵐ		
Magnetic meridian for circle east reads	269° 15′		

[1]Polarity reversed by 10 strokes of bar magnets on each face of needle.

COMPUTATION OF MAGNETIC OBSERVATIONS, APRIL 14, 1908.

The foregoing observations on course were computed in the same way as were the swing observations, explained on pages 33 to 46. It was necessary to apply to each course value of an element the proper deviation-correction, derived as explained on pages 91–92.

In the case of the declination observations given on pages 47–48, each set was computed, using Form 22 as shown on page 35. The results of the computations were as follows:

TABLE 2.—*Values of the Magnetic Declination on April 14, 1908, from A. M. Observations.*

(Latitude, 6° 01′ S; longitude, 98° 30′ W.)

Instrument	Set	Method	Local Apparent Time	Sun by Compass	Instrumental Correction			Corr'd Compass Reading	Sun's Azimuth	Obs'd Decl'n	Deviation-Corr'n	Corr'd Decl'n
					ϵ	A_{pc}	A_{sc}					
			h m s	°	°	°	°	°	°	°	°	°
R3C	1	Prism	6 12 16	N 70.79 E	+.03	+.28	......	N 71.10 E	N 80.35 E	+9.25	−.08	+9.17
R3C	2	Prism	6 24 55	70.88	+.03	+.28	......	71.19	79.98	+8.79	−.08	+8.71
R3C	1	Alidade	6 13 57	71.94	+.02	......	+.06	72.02	80.30	+8.28	−.08	+8.20
R3C	2	Alidade	6 23 14	70.94	+.03	......	+.06	71.03	80.03	+9.00	−.08	+8.92
									Means	+8.83	−.08	+8.75
D2	1	Prism	6 16 34	N 71.86 E	.00	−.54	......	N 71.32 E	N 80.23 E	+8.91	−.21	+8.70
D2	2	Prism	6 22 03	71.80	.00	−.54	......	71.26	80.07	+8.81	−.21	+8.60
D2	1	Alidade	6 18 36	70.70	+.01	......	+.04	70.75	80.18	+9.43	−.21	+9.22
D2	2	Alidade	6 20 34	71.50	+.01	......	+.04	71.55	80.12	+8.57	−.21	+8.36
									Means	+8.93	−.21	+8.72
									Weighted mean........			+8.74

TABLE 3.—*Values of the Magnetic Declination on April 14, 1908, from P. M. Observations.*

(Latitude, 5° 41′ S; longitude, 99° 55′ W.)

Instrument	Set	Method	Local Apparent Time	Sun by Compass	Instrumental Correction			Corr'd Compass Reading	Sun's Azimuth	Obs'd Decl'n	Deviation-Corr'n	Corr'd Decl'n
					ϵ	A_{pc}	A_{sc}					
			h m s	°	°	°	°	°	°	°	°	°
R3C	1	Prism	16 44 00	N 87.34 W	−.02	−.28	......	N 87.04 W	N 78.08 W	+8.96	−.08	+8.88
R3C	2	Prism	17 04 01	88.13	−.02	−.28	......	87.83	78.85	+8.98	−.08	+8.90
R3C	1	Alidade	16 46 42	87.37	−.02	......	−.03	87.32	78.20	+9.12	−.08	+9.04
R3C	2	Alidade	17 01 43	87.97	−.02	......	−.04	87.91	78.78	+9.13	−.08	+9.05
									Means	+9.05	−.08	+8.97
D2	1	Prism	16 49 25	N 86.83 W	+.10	+.54	......	N 87.47 W	N 78.30 W	+9.17	−.21	+8.96
D2	2	Prism	16 59 10	87.28	+.10	+.54	......	87.92	78.68	+9.24	−.21	+9.03
D2	1	Alidade	16 51 35	87.44	+.10	......	−.01	87.53	78.39	+9.14	−.21	+8.93
D2	2	Alidade	16 57 06	87.88	+.10	......	−.01	87.97	78.60	+9.37	−.21	+9.16
									Means	+9.23	−.21	+9.02
									Weighted mean........			+8.99

Thus, after instrumental corrections had been applied, the mean of the four sets of a. m. observations with R3C was +8°.83. The corresponding value for D2 was +8°.93. The respective deviation-corrections (see p. 92) were −0°.08 and −0°.21, giving as the final values of the magnetic declination, 8°.75 E by the standard compass (R3C) and 8°.72 E by the sea deflector (D2). The final weighted mean, compass weight 2, deflector weight 1, was 8°.74 E or 8° 44′ E, (latitude, 6° 01′ S; longitude, 98° 30′ W), as given in the Table of Results (p. 104). The standard compass, R3C, was given weight 2 as compared with

weight 1 for sea deflector, D2, because the deviation-corrections were much more strongly determined for the former instrument.

As seen from Table 3, page 55, the 4 sets of p. m. observations, with instrumental corrections applied, were +9°.05 and +9°.23, respectively, for standard compass and sea deflector. Since the course was again WSW, the deviation-corrections were the same as for the a. m. observations, viz: −0°.08 and −0°.21 respectively. The final results were 8°.97 E for the standard compass (R3C) and 9°.02 E for the sea deflector (D2), the weighted mean being 8°.99 E, or 8° 59′ E (latitude 5° 41′ S; longitude, 99° 55′ W). For explanation of instrumental corrections see page 62.

It will be observed that whereas the range in the corrected values of the declination (see last column of tables), is about 1° for the a. m. observations when the vessel was rolling from side to side 30° and more, it is but 0°.3 for the p. m. observations, although the roll of the vessel was 20°. When it is considered that a single value of the eight a. m. or p. m. sets depends upon observations made during an interval of time of about one minute, the results, under the conditions encountered, must be regarded as very satisfactory.

The horizontal-intensity observations with sea deflector 2 (D2), given on page 49 are presented in detail for two of the four sets, with each magnet 2L and 45, but for the other sets only the mean results are given in Table 4, viz, the two sets below the detailed results for each magnet. These observations were computed on Form 25, as shown on page 38, using the final value of log mC as given on page 64. The value of H resulting from the computation was 0.3282, which became 0.3304, when the deviation-correction +0.0022, page 92, was applied. The results in detail are shown in Table 4.

TABLE 4.—*Values of Horizontal Intensity with Sea Deflector 2, on April 14, 1908, P. M.*

(Latitude, 5° 41′ S; longitude, 99° 55′ W.)

Magnet	Set	H	Magnet	Set	H
		c. g. s.			*c. g. s.*
2L	1	.3292	45	1	.3280
	2	78		2	75
	3	84		3	82
	4	81		4	86
Mean.............		.3284	Mean.............		.3281
Deviation-correction.		+22	Deviation-correction.		+22
Corrected H........		.3306			.3303
		Mean 0.3304			

The total-intensity observations given on pages 50–52 were computed on Form 25*a*, as explained on pages 42–43. Final values of log C_s and log C_l, given in Table 18, page 70, were used in making this computation. The final results for long and short distances were respectively: 0.3270 and 0.3266, the mean giving 0.3268 for the horizontal intensity by deflections, while 0.3267 was the result by the loaded needle. In this case the deviation-corrections were +0.0026 and +0.0008, respectively, giving the final values of 0.3294 by deflections and 0.3275 by loaded needle. The final weighted mean of the three values of the horizontal intensity, 0.3304 by deflector, weight 3, 0.3294 by dip-circle deflections, weight 2, and 0.3275 by dip-circle loaded needle, weight 1, was 0.3296 (latitude, 5°41′S; longitude, 99° 55′ W), as given in the Table of Results (p. 104).

The satisfactory accord in the three values of H shows how completely successful were the attempts to make the sea dip-circle available for total-intensity observations, even in the lowest magnetic latitudes, and to devise as well an instrument, the sea deflector, for measuring directly horizontal intensity.

From the dip-circle observations given on pages 51–54, four values of the inclination were obtained. The results in detail, showing the various corrections applied, are given in Table 5.

TABLE 5.—*Values of the Magnetic Inclination on April 14, 1908, P. M.*
(Latitude, 5° 41′ S; longitude, 99° 55′ W.)

Instrument and method	Obs'd Incl'n	Instr'l Corr'n	Reduced Incl'n	Deviation Corr'n	Corr'd Incl'n	Weight
	°	°	°	°	°	
D. C. 189, needle 5, regular dip..................	−0.24	+0.05	−0.19	+0.25	+0.06	2
D. C. 189, needle 6, regular dip..................	−0.58	+0.05	−0.53	+0.25	−0.28	2
D. C. 189, needle 3, deflected dip, long distance....	−0.28	−0.14	−0.42	+0.25	−0.17	1
D. C. 189, needle 3, deflected dip, short distance...	+0.02	−0.12	−0.10	+0.25	+0.15	1
	Weighted means.		−0.33	+0.25	−0.08	....

The quantities in the column "Instrumental correction" were derived from Table 16, page 69. The deviation-correction $+0\overset{\circ}{.}25$ is computed on page 92. Next, the weighted mean was taken, giving to each of the values by needle 3 a weight of 1, and to the values by 5 and 6 a weight of 2 each. The resulting value of the inclination is $-0\overset{\circ}{.}08$, or 0° 05′ S, thus showing that the point of observation (latitude, 5° 41′ S; longitude, 99° 55′ W) was at the time practically on the magnetic equator.

SUMMARY OF RESULTS OF OBSERVATIONS MADE ON COURSE, APRIL 14, 1908.

Summarizing, we have the results given in Table 6.

TABLE 6.—*Results of Magnetic Observations on April 14, 1908.*

Station	Latitude	Long. East of Gr.	Declination					Inclination					Horizontal Intensity				
			L.M.T.	Value	Instr.	Obs'r	p[3]	L.M.T.	Value	Instr.	Obs'r	p[3]	L.M.T.	Value	Instr.	Obs'r	p[3]
	° ′	° ′	h	°				h	°				h	c. g. s.			
187 G III[1]	6 01 S	261 30	6.3	8.75 E	R3C	WJP	2	.....	....	....	....	..	.....	......	....	....	...
			6.3	8.72 E	D2	PHD	1	.....	....	....	....	..	.....	......	....	....	...
	Weighted mean.......			8.74 E (8° 44′ E)	......	....	...	.....	....	....	....	..	.....	......	....	....	...
188 G III[2]	5 41 S	260 05	16.9	8.97 E	R3C	WJP	2	16.9	+0.06	[4]189.5	PHD	2	16.9	.3304	[8]D2	DCS	3
			16.9	9.02 E	D2	DCS	1	16.9	−0.28	[5]189.6	PHD	2	16.9	.3294	[9]189.34SL	PHD	2
			.....	....	......	....	...	16.9	−0.17	[6]189.3L	PHD	1	16.9	.3275	[10]189.4	PHD	1
			.....	....	......	....	...	16.9	+0.15	[7]189.3S	PHD	1	.....	......	....	....	...
	Weighted means......			8.99 E (8° 59′ E)	......	....	...	.....	−0.08 (0° 05′ S)	....	....	..	.....	.3296	....	....	...

[1]Course, WSW; roll, 30°; sea *M*; weather, *bc*.

[2]Course, W for inclination and intensity observations. For the declination observations it was necessary to change the course to WSW in order that the Sun would not be obscured by masts or rigging. Roll, 20° during declination observations, and 30° while inclination and intensities were being observed; sea, *M*; weather, *bc*.

[3]This is the *combining* weight for use when taking the weighted mean of individual values. It is not to be confused with the "weight" which appears in the Table of Results (p. 104). The latter is intended to give an approximate measure of the reliability of a result according to conditions encountered. Thus, to the results on April 14, 1908 a weight of 2 was assigned in the table (see explanation, p. 95).

[4]See dip-circle 189, needle 5, regular dip.

[5]See dip-circle 189, needle 6, regular dip.

[6]See dip-circle 189, needle 3, deflected dip, long distance.

[7]See dip-circle 189, needle 3, deflected dip, short distance.

[8]See deflector 2.

[9]See dip-circle 189, deflection observations, needles 3 and 4, short and long distance.

[10]See dip-circle 189, loaded-dip observations, needle 4.

SHORE MAGNETIC WORK.

Mention occurs on page 15 of shore magnetic observations being made at every port visited by the vessel. Specimens of the usual land observations will be found in Volume I, pages 30–41. The corrections for the various instruments on the adopted standards will be found on pages 76–77.

The results of the shore observations and descriptions of stations are given on pages 105–114.

DETERMINATION OF GEOGRAPHIC POSITION AT SEA.

GENERAL METHODS.

It would avail little to strive for the highest accuracy in the values of magnetic elements at sea if the corresponding geographic position were not well determined at the same time. There are regions in the Pacific, as well as in other portions of the globe, where the magnetic declination and inclination vary almost as rapidly as the geographic coordinates expressed in the same units. It is therefore of vital importance to secure the closest approximation possible to the true geographic position corresponding to the time of the magnetic results, particularly at sea, where the ship's position is changing continuously. If it were possible to determine simultaneously both geographic coordinates at the middle of the magnetic observations, or at instants whose mean would correspond to the middle of the magnetic observation, the problem would be comparatively simple and the desired accuracy might be readily secured.

Opportunities for simultaneous determinations of both coordinates have sometimes occurred for several days in succession, when either the Moon or some very bright star, visible in daylight, was favorably situated with regard to the Sun about the middle of magnetic observations. Such opportunities are never missed, as the geographic position thus determined is final, if the chronometer rate assumed is found to have been satisfactory. Usually, however, as the Sun only is available in the day, and stars only during twilight, since the horizon is lost in the later darkness, the geographic coordinates must be determined, in succession, as the Sun changes in azimuth and as the ship sails from point to point. The customary procedure, therefore, has been to observe the Sun's altitude in the morning, at noon, and in the afternoon, and the altitudes of stars at dusk. The ship's changes of position during the day were determined from the course or courses sailed and the distances recorded by a taffrail log. Whenever feasible the altitudes of three different stars were observed, to eliminate, as far as possible, both instrumental and observational errors.

The *geographic position at the time of magnetic observations* was determined by computing the changes in latitude and longitude from the preceding position fixed by astronomic observations, then noting the differences in the latitude and longitude of the following astronomic station, as computed by the course and distance run (the dead reckoning), and as given by the astronomic observations. These errors of run in latitude and longitude were distributed over the distance run proportionally to the time elapsed. Such distribution of the error of dead reckoning is based on the assumption that the causes producing the error, be it current, drift, leeway, or bad steering, are constant throughout the period considered.

Thus, on April 14, 1908, there were magnetic-declination observations (see p. 47) about 6 a. m., ship's time, followed by two altitudes of the Sun about 9 a. m., two latitude observations at noon, and two altitudes of the Sun in the middle of the magnetic observations. The altitudes were taken in each case by observers D.C.S. and P.H.D. Finally, altitudes of Canopus, Jupiter, and Rigel were measured at twilight, thus completely controlling the changes in latitude and longitude throughout the day.

Forms.—As in the magnetic observations and computations, forms are also used in the work of determining the ship's position. They not only lead to a systematic record of the observations and computations, but are also great aids to the computer and reviser. Three forms are used: one for the dead reckoning, one for the longitude, and one for the latitude. This method of navigation lends itself readily to the subsequent operations of correcting the positions for both the error in the course and distance sailed and for the error in the chronometer rates used at sea. Latitude observations were usually made by three observers with different sextants, following the usual practice at sea of noting the maximum altitude at noon. Sun-longitude observations were usually made by at least two observers with different sextants, six altitudes in rapid succession being measured by each observer. When three stars were available at twilight observations, two or three altitudes of each one were measured in succession, followed by an equal number of altitudes of the same stars taken in the reverse order, so that the mean altitude of each star corresponded very closely to the same instant. In order to expedite the work, readings were entered directly on the forms by a recorder, who also noted the times. Both before and after observations, the time-piece used was compared with the chronometer selected as a standard, and as all the chronometers were also intercompared daily it was possible to determine the longitude by each one separately. This, in fact, has been done in the office revision.

Before leaving port the chronometer rates were determined by comparison with standard-time signals, or by local time-determinations with sextant and artificial horizon at intervals of seven to ten days. The rates thus determined were accepted and used until the next port was reached, when the errors resulting from the accepted rates were determined and the preceding longitudes were corrected accordingly. Every longitude of a magnetic station at sea, therefore, depends upon the controlled rates of from three to five chronometers.

The value of the dip of the sea horizon received considerable attention. When possible, back altitudes through the zenith to the opposite horizon were measured, but the application of this method was restricted practically to altitudes of the Sun in the equatorial regions. On Cruise III of the *Galilee* the dip of the horizon by the Pulfrich dip-measurer was applied to each altitude observed in daylight. Occasionally also on this cruise altitudes were attempted with the gyroscopic octant constructed by Ponthus and Therrode, but the operation was found to be so difficult, owing to the motion of the ship, that this method was soon abandoned. On a larger and steadier vessel this instrument might be more practical. It may be stated here that the many checks on the altitudes measured during Cruises II and III of the *Galilee*, and the observations with the Pulfrich dip-measurer, gave no indication of abnormal refraction or apparent dip of the horizon beyond the limits of precision of the instruments used. However, it must be admitted that sextant observations on the *Galilee*, where checks on the altitudes were available, were made mostly upon the deep sea and in regions where there was no very large difference between sea-temperatures and air-temperatures.

Sextant index-corrections were determined every few days by star-methods or Sun-methods.

Specimen observations for the determination of geographic position will be found given in connection with the work of the *Carnegie* (see pp. 226–230).

ACCURACY OF POSITIONS AT SEA.

Accuracy of geographic positions is dependent on so many factors that it is quite impossible to define it by exact figures based on any one investigation of numerical results. The first consideration would naturally be the magnitude of the probable error of the measured altitudes, and, if the observation were a meridional one, this probable error would be the probable error of the resultant latitude at the instant of observation. But as it rarely happens that this instant corresponds to the time of a magnetic observation, the observed

latitude must be altered by a quantity which depends upon the run of the ship between observed latitude and the place of the magnetic observations.

The error in run may be controlled by the astronomic observations immediately preceding and following the magnetic observations. This procedure is, in fact, the method employed in the ocean work. But in attempting to assign limits of accuracy we are again confronted with the error in this control which depends on stability of speed and direction of ocean currents, and upon constancy of leeway and steering. Again, if the observed Sun or star be east or west of the meridian, there is an additional uncertainty introduced by the unknown error in the assumed chronometer-rate. This error, however, need not be considered in the case of the *Galilee* and *Carnegie*, since it was controlled by time comparisons at every port available for the purpose, and was distributed back when appreciable. An investigation of some of the three-star determinations of the ship's position made on the *Galilee* indicates that if the Sun or star be favorably situated and the weather and sea conditions fair, the average error to be expected in the determination of the geographic position is less than 2 miles. The error in the control of the "error of run" is usually insignificant if the controlling astronomic observations are not more than 6 hours apart. This has usually been the case in the *Galilee* and *Carnegie* observations, except in high latitudes, where fog and clouds prevail. Of course, there are exceptional times when no astronomic observations are possible for several days. The geographic positions for the results of magnetic inclination and intensity are then more or less uncertain. In the case of magnetic-declination results, however, the Sun or star that serves for the declination observations usually permits of at least a fairly good determination of position. (See Pl. 2, Fig. 4.)

REDUCTION FORMULÆ AND DETERMINATION OF CONSTANTS.

CONSTANTS AND CORRECTIONS FOR SEA INSTRUMENTS.

The instrumental constants and reductions to standards (see p. 77) of the sea instruments used in the *Galilee* work were determined at Washington and at the various ports visited by comparison with standardized land instruments. The method adopted in these comparisons was that of simultaneous observations, except during the earlier work, when the method of alternate observations was used. In order to refer values of the magnetic elements at one observing station to any of the other stations, station-differences were carefully determined at each port from the observations with the land instruments, following the methods described in Volume I (pp. 19, 20).

DECLINATION OBSERVATIONS.

Standard compass and azimuth circle.—For specimen declination-observations with the standard Ritchie compass and azimuth circle on board ship, and the corresponding computations, see pages 47–48 and 55. The purely instrumental corrections for the compass and azimuth circle arise from (1) card-graduation error and eccentricity of card mounting, (2) index error, and (3) lack of correct adjustment of the azimuth-circle attachments. Card-graduation errors and index errors were determined at shore stations by observing the magnetic azimuths of a series of 6 or more marks in the horizon, *i. e.*, at altitude practically 0°, the marks being selected to give as nearly equal angular distribution as possible. The magnetic azimuths were controlled by simultaneous declination-observations with a standardized magnetometer at a second station. For each instrument the total periodic errors of the compass-card readings, determined in this way at a number of stations, were plotted with the total errors as ordinates and card readings as abscissæ, and a mean curve was drawn. The mean ordinate of the resulting graph represents the index correction, x, of the compass and azimuth circle, for altitude, $h = 0°$; the ordinates of the graph referred to a new axis of abscissæ at a distance x from the old one are the purely periodic corrections, ϵ. The corrections, A_{ps} or A_{ss}, arising from any lack of correct adjustment of the azimuth-circle attachments

for the method of sighting used, viz, prism or alidade, may be represented by the formula (see pp. 134–140)

$$A_{ps} \text{ or } A_{as} = x + y \tan h + z \tan h \tan \frac{h}{2} + w \tan h \sec \frac{h}{2}$$

in which x is the index correction as above determined, h is the altitude of the celestial body observed, and y, z, and w are coefficients which may be determined by least-square adjustment of a number of observations at different altitudes. The data for the establishment of such a formula for the azimuth circle of each compass were secured at the shore stations from series of observations made on the Sun with this instrument to determine the magnetic declination. The absolute values of the magnetic declination were determined from observations with the standardized magnetometer. Depending upon the sighting device (prism or alidade) used, the total correction then, is either $\epsilon + A_{ps}$ or $\epsilon + A_{as}$.

Each of the terms making up the total correction to observed card-reading, viz, ϵ and A_{ps} or A_{as}, is given separately in this section for each compass and azimuth circle. *The signs attached are in the sense of continuous graduation from the south point as 0° through 360° in a clockwise direction;* therefore all card readings in the southwest and northeast quadrants—that is, all readings from S to S 90° W (or W) and from N to N 90° E (or E)—must be numerically increased when the sign given for ϵ, A_{ps}, or A_{as} is plus (+), while all card readings in the other two quadrants must be numerically decreased when the sign given for ϵ, A_{ps}, or A_{as} is plus (+), and vice versa.

Standard Ritchie compass 29971 with azimuth circle 387-III (R1A).—The prism method alone was used with this equipment, which was on board during Cruise I. The corrections were included and applied in the ship's deviations, comparisons having been made directly between declinations observed on board and corresponding values observed on shore with the standardized magnetometer.

Standard Ritchie compass 29971 with azimuth circle 418-III (R1B).—The adopted periodic corrections to observed card-readings of compass R1B, used on Cruise II, are as follows:

TABLE 7.—*Periodic Corrections to Card Readings of Compass R1B.*

Card Reading	ϵ	Card Reading	ϵ	Card Reading	ϵ	Card Reading	ϵ
	°		°		°		°
South	−0.09	West	+0.08	North	−0.11	East	+0.07
S 10° W	− .03	N 80° W	+ .06	N 10° E	− .10	S 80° E	+ .02
S 20° W	+ .03	N 70° W	+ .04	N 20° E	− .05	S 70° E	− .03
S 30° W	+ .08	N 60° W	+ .01	N 30° E	+ .04	S 60° E	− .09
S 40° W	+ .12	N 50° W	− .02	N 40° E	+ .12	S 50° E	− .14
S 50° W	+ .14	N 40° W	− .04	N 50° E	+ .18	S 40° E	− .19
S 60° W	+ .15	N 30° W	− .06	N 60° E	+ .18	S 30° E	− .21
S 70° W	+ .14	N 20° W	− .09	N 70° E	+ .16	S 20° E	− .20
S 80° W	+ .11	N 10° W	− .10	N 80° E	+ .12	S 10° E	− .16

The correction, A_{ps}, to observed card-readings by the prism method was found to be independent of the Sun's altitude, but there were two marked changes in its value; the values adopted are

$A_{ps} = +1.^{\circ}10$ from February 14 to April 25, 1906
$A_{ps} = -0.^{\circ}62$ from May 10 to May 18, 1906
$A_{ps} = +0.^{\circ}18$ from May 20 to October, 1906

The adopted correction, A_{as}, to observed card-readings by the alidade method, deduced from a least-square adjustment of all available data, varies with the Sun's altitude, h, and is given by the formula

$$A_{as} = +0.^{\circ}13 + 0.^{\circ}00 \tan h - 1.^{\circ}06 \tan h \tan \frac{h}{2} + 0.^{\circ}30 \tan h \sec \frac{h}{2}$$

Standard Ritchie compass 29499 with azimuth circle 481-III (R3C).—The adopted periodic corrections to observed card-readings of compass R3C, used on Cruise III, are given in Table 8.

TABLE 8.—*Periodic Corrections to Card Readings of Compass R3C.*

Card Reading	ϵ	Card Reading	ϵ	Card Reading	ϵ	Card Reading	ϵ
	°		°		°		°
South	+0.06	West	+0.02	North	−0.07	East	−0.03
S 10° W	+ .08	N 80° W	+ .01	N 10° E	− .06	S 80° E	− .05
S 20° W	+ .08	N 70° W	− .01	N 20° E	− .04	S 70° E	− .07
S 30° W	+ .07	N 60° W	− .03	N 30° E	.00	S 60° E	− .08
S 40° W	+ .07	N 50° W	− .04	N 40° E	+ .03	S 50° E	− .07
S 50° W	+ .05	N 40° W	− .06	N 50° E	+ .05	S 40° E	− .05
S 60° W	+ .04	N 30° W	− .08	N 60° E	+ .05	S 30° E	− .02
S 70° W	+ .03	N 20° W	− .08	N 70° E	+ .03	S 20° E	+ .02
S 80° W	+ .03	N 10° W	− .08	N 80° E	.00	S 10° E	+ .04

The value adopted for the correction, A_{pc}, to observed card-readings by the prism method is for all altitudes

$$A_{pc} = +0\overset{\circ}{.}28$$

The adopted correction to observed card-readings by the alidade method, deduced from a least-square adjustment of all available data, varies with the Sun's altitude, h, and is given by the formula (see p. 140)

$$A_{ac} = +0\overset{\circ}{.}06 - 1\overset{\circ}{.}68 \tan h - 1\overset{\circ}{.}17 \tan h \tan\frac{h}{2} + 1\overset{\circ}{.}75 \tan h \sec\frac{h}{2}$$

Negus compass 31974 with Negus azimuth circle (D1).—Declinations obtained by this compass and azimuth circle during Cruises I, II, and III (to July 18, 1907) were used only as checks upon values by compasses R1A, R1B, and R3C.

Ritchie compass 33566 with azimuth circle 483-III (D2).—The adopted periodic corrections to observed card readings of compass D2, used on Cruise III beginning August 1907, are given in Table 9.

TABLE 9.—*Periodic Corrections to Card Readings of Compass D2.*

Card Reading	ϵ	Card Reading	ϵ	Card Reading	ϵ	Card Reading	ϵ
	°		°		°		°
South	−0.02	West	−0.10	North	+0.13	East	−0.06
S 10° W	− .01	N 80° W	− .10	N 10° E	+ .14	S 80° E	− .09
S 20° W	− .01	N 70° W	− .08	N 20° E	+ .14	S 70° E	− .12
S 30° W	− .02	N 60° W	− .05	N 30° E	+ .12	S 60° E	− .14
S 40° W	− .03	N 50° W	− .02	N 40° E	+ .09	S 50° E	− .13
S 50° W	− .04	N 40° W	+ .01	N 50° E	+ .06	S 40° E	− .11
S 60° W	− .06	N 30° W	+ .04	N 60° E	+ .04	S 30° E	− .08
S 70° W	− .08	N 20° W	+ .08	N 70° E	+ .01	S 20° E	− .05
S 80° W	− .09	N 10° W	+ .10	N 80° E	− .02	S 10° E	− .03

The adopted correction, A_{pc}, to observed card-readings by the prism method is for all altitudes

$$A_{pc} = -0\overset{\circ}{.}54$$

The adopted correction, A_{ac}, to card readings by the alidade method, deduced from a least-square adjustment of all available data, varies with the Sun's altitude, h, and is given by the formula

$$A_{ac} = +0\overset{\circ}{.}06 - 1\overset{\circ}{.}63 \tan h + 0\overset{\circ}{.}91 \tan h \tan\frac{h}{2} + 1\overset{\circ}{.}33 \tan h \sec\frac{h}{2}$$

Kelvin compass and azimuth instrument (*K*).—Declination results by the Kelvin dry compass and azimuth instrument were for the most part experimental and were used only as checks upon determinations by the other compasses and azimuth circles.

HORIZONTAL-INTENSITY OBSERVATIONS.

Sea deflector for horizontal-intensity observations.—As shown in specimen Form 25, page 38, the horizontal intensity is computed from sea-deflector observations by the formula

$$H = \frac{mC}{\sin u}$$

in which m is the magnetic moment of the deflecting magnet, C is a constant involving the deflection distance (r), the distribution coefficients (P and Q), and the induction factor μ, and u is the observed angular deflection produced by the deflecting magnet when its axis is perpendicular to that of the compass card. The sea deflector is a relative instrument and values of the so-called constant, $mC = H \sin u$, must be determined from comparison horizontal-intensity observations made at shore stations with standardized absolute instruments. The constant, mC, is subject to changes arising from (1) decrease in m with time, (2) effects of temperature variations on m and r, and (3) effects of changes in vertical intensity, Z. In the *Galilee* work, except as noted below under constants for Cruise I, all available data for log mC were subjected to a least-square adjustment based on the general formula

$$\log mC = \log mC_{20} \text{ at } \tau_0 + x\Delta\tau + y(\Delta\tau)^2 + q(20° - t)$$

in which τ is the epoch of observation expressed in years, τ_0 is the selected reference epoch, $\Delta\tau$ is $(\tau - \tau_0)$, q is the factor representing the combined effect of a change in temperature of 1° centigrade on m and C (on the latter because of change in r), and t is the temperature of observation; the standard temperature of reference is 20° centigrade. Instead of deriving all the unknowns in above equation simultaneously, it was found better to make a separate determination of the temperature factor, q, selecting the observations best suited for this purpose. The final results were arrived at by a process of successive approximations, in the last steps of which q was treated as a constant.

As will be noted, the general form contains no term to correct for effects of changes in vertical intensity (Z). In the *Galilee* work it is reasonable to assume that such effects were at no time in excess of those determined for the improved and more accurate revolving-compass pattern of sea deflector used on board the *Carnegie*. In the case of that instrument the maximum effect (see pp. 238–239) on log mC, corrected for time and temperature, was, for the extreme range in Z, of the order 0.0020, which is equivalent to less than $0.005H$; in general, the correction for the ΔZ-effect would be less than half of that amount. Moreover, the ΔZ-effect was partly eliminated by the introduction of the $(\Delta\tau)^2$-term in the adjustment of the constant observations made at widely distributed ports. It is a fair assumption therefore, that the introduction of an additional term in log mC, to correct for outstanding effects of changes in Z, would probably not change the values computed by the adopted formulæ more than $0.0015H$ in the extreme case. With the compass-azimuth-circle pattern of sea deflector used during the *Galilee* cruises, the error of observation at sea is about of the order $0.002H$; a recomputation is, therefore, not warranted—especially since, in general, the values given in the present volume are the means of both deflector and dip-circle determinations.

Sea deflector (*D1*).—For Cruise I, the adopted values of log mC are the means of all shore observations, the available data being insufficient for a reliable determination of a time-change coefficient for the short period of this cruise. The constants adopted from August 2 to December 13, 1905, for the 2 positions of the deflecting magnets in their housings,

viz, "letters up" and "letters down" (designated respectively U and D), and at the short deflection-distances are

$$\begin{array}{ll}\text{Magnet 45 }(U) & \log mC = 9.00673 + 0.00019(20^\circ - t)\\ \text{Magnet 45 }(D) & \log mC = 9.00673 + 0.00019(20^\circ - t)\\ \text{Magnet NL}(U) & \log mC = 8.94312 + 0.00016(20^\circ - t)\\ \text{Magnet NL}(D) & \log mC = 8.94213 + 0.00016(20^\circ - t)\end{array}$$

Values of horizontal intensity computed with those constants were reduced to C. I. W. Standard (see p. 77) by applying a correction of $-0.00047H$.

For Cruises II and III (to July 1907), the constants adopted on the basis of C. I. W. Standard (see p. 77) for the short deflection-distances are

$$\begin{array}{ll}\text{Magnet 45 (both } U \text{ and } D) & \log mC = 9.00519 + 0.00171\Delta\tau - 0.00068(\Delta\tau)^2\\ & \quad + 0.00020(20^\circ - t)\\ \text{Magnet NL (both } U \text{ and } D) & \log mC = 8.94392 - 0.01627\Delta\tau + 0.00369(\Delta\tau)^2\\ & \quad + 0.00015(20^\circ - t)\end{array}$$

in which $\Delta\tau = \tau - 1906.00$.

There is a periodic correction to log mC for sea deflector 1, which, however, has been treated as a part of the ship's deviations, since it depends upon the orientation of the lubber-line, *i. e.*, the heading of the ship. The equation for Cruises II and III representing the mean value of that correction for magnets 45 and NL is therefore given merely as a matter of interest; it is

$$\delta \log mC = -0.0002 \sin \zeta + 0.0003 \cos \zeta - 0.0006 \sin 2\zeta - 0.0023 \cos 2\zeta$$

where ζ is the compass reading of the forward lubber-line, reckoned continuously from north through east.

Sea deflector 2 ($D2$).—The constants adopted on the basis of C. I. W. Standard (see p. 77) for the period August 1907 to May 1908, for the short deflection-distances are

$$\begin{array}{ll}\text{Magnet 45} & \log mC = 8.93126 - 0.00074\Delta\tau - 0.00107(\Delta\tau)^2 + 0.00020(20^\circ - t)\\ \text{Magnet 2L} & \log mC = 8.80412 - 0.00276\Delta\tau + 0.00127(\Delta\tau)^2 + 0.00017(20^\circ - t)\end{array}$$

in which $\Delta\tau = \tau - 1908.00$. It should be noted that for sea deflector 2 each magnet had only one possible position relative to the apparatus when mounted.

As in the case of sea deflector 1, there is a periodic correction to log mC for sea deflector 2, which again has been treated as a part of the ship's deviations, since it depends upon the orientation of the lubber-line, *i. e.*, the heading of the ship. The equation representing the mean value of that correction for magnets 45 and 2L is therefore given merely as a matter of interest; it is

$$\delta \log mC = +0.0001 \sin \zeta - 0.0001 \cos \zeta - 0.0005 \sin 2\zeta + 0.0007 \cos 2\zeta$$

where ζ is the compass reading of the forward lubber-line reckoned continuously from north through east.

INCLINATION OBSERVATIONS.

Sea dip-circle.—Specimen observations and computations for the determination of inclination, I, by the sea dip-circle, from both the dipping-needle and the deflected-needle methods, are fully shown on pages 50–54. Values for dip-needle corrections were determined at Washington and the various shore stations by comparisons between the sea dip-circles and standardized dip-circles or earth-inductors. Since observations on board ship were made frequently with one polarity only, it was necessary to determine the so-called balance-error arising from any eccentricity of the center of gravity of the needle. For each needle the correction due to that error is determined from graphs representing the quantity $\frac{1}{2}(I_A - I_B)$, for different inclinations. I_A is the inclination observed when the end of the

needle marked A is the north-seeking end, and I_B is the corresponding inclination observed when the end marked B is the north-seeking end; inclination is reckoned as positive when the north-seeking end of the needle points below the horizon. Both shore and sea data were utilized for the determination of the graphs for $\frac{1}{2}(I_A - I_B)$. In addition to the balance error there is also the error due to the irregularity of the pivots, which will vary, in general, with the magnetic field. To show the variation of the dip-needle correction, ΔI, with total intensity, F, and inclination, I, there was established for each needle, from all available comparison-data, by the method of least squares, an expression of the following general form (see Volume I, p. 45):

$$F\Delta I = x + z\cos I + y\sin I$$

The adopted values of the coefficients, x, z, and y, for each needle are given on pages 66–69.

TOTAL-INTENSITY OBSERVATIONS.

Sea dip-circle.—As already stated (pp. 21–22) the Lloyd-Creak type of sea dip-circle was modified after Cruise I to make possible the use of Lloyd's method to determine the total intensity, F, as well as the inclination, I, in all magnetic latitudes. Complete specimen observations and reductions are shown on pages 40–42, and 50–52. The value of the horizontal intensity, H, is obtained by the formula

$$H = F\cos I$$

As the method employed is a relative one, it is essential that no change be made in the weight used with the loaded-dip needle, and that its position be not shifted during a cruise from one end of the needle to the other; furthermore, the magnetism of the loaded-dip and deflected needles, except for the normal changes with time, must remain unchanged. The reduction formulæ for the total intensity, F, are as given below. Replacing F by $H\sec I$, the corresponding expressions for H are derived.

Loaded-dip observations only,	$F = C_l \cos I' \csc u$
Deflection observations only,	$F = C_d \csc u_1$
Both loaded-dip and deflection observations,	$F = C\sqrt{\cos I' \csc u \csc u_1}$

where I' is the loaded-dip angle, u_1 is the single-deflection angle, $u = I - I'$, C_l is the loaded-dip constant $= \frac{K}{m}$, C_d is the deflected-dip constant $= K_1 m$, and C is the combined constant $= \sqrt{K K_1}$. The constants C_l and C_d involve the magnetic moment, m, of the loaded dip-needle and are both, therefore, subject to change with temperature and with time. C_l furthermore involves the induction correction, which is a function of F. C_d is affected also by changes in deflection distances caused by temperature changes, and by any changes in the distribution coefficients. Two deflection-distances, designated short (S) and long (L), are provided in the modified sea dip-circle (see p. 22), and thus there are two independent sets of constants. There are also two positions, designated "direct" (D) and "reversed" (R), for the deflected or suspended needle during deflection observations; "direct" position means that the face of the deflected needle is towards the face of the vertical circle; "reversed" position means that the face of the deflected needle is towards the back of the vertical circle. Thus, since the deflection observations on board ship may be for one distance and in one position only, the constants to be controlled by shore observations are C_l, C_{dD} for S, C_{dR} for S, C_{dD} for L, and C_{dR} for L. Values for these intensity constants were determined at Washington and at each shore station visited by means of comparisons between the sea dip-circles and standardized land magnetometers and dip instruments.

SEA DIP-CIRCLE CORRECTIONS.

The adopted inclination-corrections and intensity-constants are given below for each sea dip-circle. All corrections, unless otherwise noted, are on the basis of C. I. W. Standards. The inclination corrections for the dip needles apply to complete dip determinations by both polarities, and for the deflected needle to dip determinations made in both "direct" and "reversed" positions. For the sea observations, when the dip was observed with only one polarity of needle, the correction to obtain the mean value for both polarities is taken from the table of "half polarity-differences." Thus (see p. 64), either

$$I = I_B + \frac{1}{2}(I_A - I_B), \quad \text{or} \quad I = I_A - \frac{1}{2}(I_A - I_B).$$

All inclination values are referred to north-seeking end of needle, inclination of north-seeking end of needle below the horizon being reckoned positive. All values of total intensity and horizontal intensity are reckoned positive; values of the vertical intensity are given the same signs as the corresponding inclinations.

Whenever a listed needle is not a part of the circle to which reference is made it is followed by the number of the circle to which it belongs; thus, 5 of 163 means needle No. 5 of dip circle No. 163. The quantities ΔI and F in the formulæ are always expressed, respectively, in minutes of arc and in C. G. S. units.

Sea dip-circle 35.—Sea dip-circle 35 (Dover No. 168), loaned by the United States Coast and Geodetic Survey, was used for some experimental work preceding Cruise I and, after being reconstructed (see p. 21), for observations on board the *Galilee* during Cruises II and III (to July 1907). The dip and intensity needles for this instrument are listed in the inventory of instruments (see pp. 30–31).

The adopted formulæ resulting from least-square adjustments of all available data for corrections to observed inclinations are given in Table 10.

TABLE 10.—*Inclination Corrections for Sea Dip-Circle 35.*

Number of— Suspended Needle	Number of— Deflecting Needle	Deflection Distance	Formulæ for Inclination Corrections
For observations preceding Cruise I			
1 and 2	....	....	$\Delta I = -2'.6$
For observations during Cruise II			
2	....	....	$F\Delta I = -12'.8 - 14'.2 \cos I + 4'.0 \sin I$
5 of 163	....	....	$F\Delta I = -2.7 + 4.0 \cos I - 2.7 \sin I$
3*D*	4 of 35[1]	Short	$\Delta I = +7.2$
3*R*	4 of 35[1]	Short	$\Delta I = +11.5$
3*D*	4 of 35[1]	Long	$\Delta I = -2.1$
3*R*	4 of 35[1]	Long	$\Delta I = -0.3$
3*D*	8 of 163	Short	$F\Delta I = +35.6 - 40.7 \cos I - 3.4 \sin I$
3*R*	8 of 163	Short	$F\Delta I = +34.6 - 40.7 \cos I - 3.4 \sin I$
3*D*	8 of 163	Long	$F\Delta I = -1.9 + 4.1 \cos I - 3.4 \sin I$
3*R*	8 of 163	Long	$F\Delta I = -1.1 + 4.1 \cos I - 3.4 \sin I$
3*D*	4 of 169[1]	Short	$\Delta I = +7.5$
3*R*	4 of 169[1]	Short	$\Delta I = +9.5$
3*D*	4 of 169[1]	Long	$\Delta I = -8.3$
3*R*	4 of 169[1]	Long	$\Delta I = -12.9$
For observations during Cruise III (to July 1907)			
1	....	....	$F\Delta I = +2'.7 - 1'.4 \cos I - 3'.6 \sin I$
2	....	....	$F\Delta I = +9.2 - 9.4 \cos I - 4.8 \sin I$
3*D*	4	Short	$F\Delta I = +21.9 - 28.6 \cos I - 8.7 \sin I$
3*R*	4	Short	$F\Delta I = +17.4 - 18.9 \cos I - 9.4 \sin I$
3*D*	4	Long	$F\Delta I = +18.4 - 22.4 \cos I - 9.2 \sin I$
3*R*	4	Long	$F\Delta I = +8.0 - 9.7 \cos I - 3.4 \sin I$

[1]Needles 4 of circle 35 and 169 were used for short periods only (see footnotes, Table 12). Available data are insufficient for showing variation of ΔI with F and I.

From Table 11, the "half polarity-differences" are obtained for sea dip-circle 35, as based on all available data.

TABLE 11.—*Half Polarity-Differences for Sea Dip-Circle 35.*

Inclination	$\frac{1}{2}(I_A - I_B)$ for Needle		Inclination	$\frac{1}{2}(I_A - I_B)$ for Needle		Inclination	$\frac{1}{2}(I_A - I_B)$ for Needle	
For observations during Cruise II								
	No. 2	No. 5 of 163		No. 2	No. 5 of 163		No. 2	No. 5 of 163
°	′	′	°	′	′	°	′	′
+60	+0.5	+2.0	+20	− 6.2	+10.5	−20	− 4.0	+ 8.8
+50	−2.0	+5.0	+10	− 6.4	+11.5	−30	− 2.5	+ 6.5
+40	−4.0	+7.2	0	− 6.0	+11.0	−40	− 1.0	+ 4.0
+30	−5.5	+9.2	−10	− 5.2	+10.0			
For observations during Cruise III (to July 1907)								
	No. 1	No. 2		No. 1	No. 2		No. 1	No. 2
°	′	′	°	′	′	°	′	′
+80	+5.0	+3.8	+30	+ 8.2	− 2.5	−20	+12.0	− 8.8
+70	+5.6	+2.5	+20	+ 9.0	− 3.8	−30	+12.6	−10.0
+60	+6.2	+1.2	+10	+ 9.8	− 5.0	−40	+13.2	−11.2
+50	+6.9	0.0	0	+10.5	− 6.2			
+40	+7.5	−1.2	−10	+11.2	− 7.5			

The adopted formulæ resulting from least-square adjustments of all available data for the logarithms of the total-intensity constants are given in Table 12.

TABLE 12.—*Intensity Constants for Sea Dip-Circle 35.*

Number of— Suspended Needle	Number of— Deflecting Needle	Deflection Distance	No. of Weight in Loaded Needle	Logarithms of the Intensity Constants
For observations during Cruise II; $\Delta\tau = (\tau - 1906.00)$				
4[1]	....	....	6	$C_l = 9.76282 - 0.00010\,(20^\circ - t)$
3*D*	4	Short	....	$C_d = 9.46576 + 0.00010\,(20 - t)$
3*R*	4	Short	....	$C_d = 9.46803 + 0.00010\,(20 - t)$
3*D*	4	Long	....	$C_d = 9.31503 + 0.00010\,(20 - t)$
3*R*	4	Long	....	$C_d = 9.31717 + 0.00010\,(20 - t)$
8 of 163	....	....	6 of 35	$C_l = 9.67407 + 0.09485\,\Delta\tau - 0.09445\,(\Delta\tau)^2 - 0.00010\,(20^\circ - t)$
3*D*	8 of 163	Short	....	$C_d = 9.52213 + 0.02476\,\Delta\tau - 0.05349\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
3*R*	8 of 163	Short	....	$C_d = 9.52405 + 0.02476\,\Delta\tau - 0.05349\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
3*D*	8 of 163	Long	....	$C_d = 9.38972 - 0.07311\,\Delta\tau + 0.06611\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
3*R*	8 of 163	Long	....	$C_d = 9.39180 - 0.07311\,\Delta\tau + 0.06611\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
4 of 169[2]	....	....	(?)	$C_l = 9.42481 + 0.00572\,\Delta\tau - 0.00010\,(20^\circ - t)$
3*D*	4 of 169	Short	....	$C_d = 9.50482 - 0.01294\,\Delta\tau + 0.00010\,(20 - t)$
3*R*	4 of 169	Short	....	$C_d = 9.50686 - 0.01294\,\Delta\tau + 0.00010\,(20 - t)$
3*D*	4 of 169	Long	....	$C_d = 9.35502 - 0.00778\,\Delta\tau + 0.00010\,(20 - t)$
3*R*	4 of 169	Long	....	$C_d = 9.35720 - 0.00778\,\Delta\tau + 0.00010\,(20 - t)$
For observations during Cruise III (to July 1907); $\Delta\tau = (\tau - 1908.00)$				
4	....	....	6	$C_l = 9.78394 + 0.00187\,\Delta\tau - 0.01008\,(\Delta\tau)^2 - 0.00010\,(20^\circ - t)$
3*D*	4	Short	....	$C_d = 9.45904 - 0.01900\,\Delta\tau - 0.00870\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
3*R*	4	Short	....	$C_d = 9.46124 - 0.01900\,\Delta\tau - 0.00870\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
3*D*	4	Long	....	$C_d = 9.30957 - 0.00403\,\Delta\tau + 0.00529\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
3*R*	4	Long	....	$C_d = 9.31177 - 0.00403\,\Delta\tau + 0.00529\,(\Delta\tau)^2 + 0.00010\,(20 - t)$

[1]Axle of loaded-dip needle 4 was broken during swing observations Feb. 16, 1906; the mean observed values of intensity constants are adopted for short period, during which needle 4 was used with needle 3.

[2]Loaded-dip needle 8 of circle 163 was replaced at Yokohama Aug. 23, 1906, by needle 4 of circle 169. The intensity constants were determined only at two shore stations, viz. Tokio and San Diego; hence, available data are insufficient for deriving coefficients of $(\Delta\tau)^2$-terms.

Sea dip-circle 169.—Sea dip-circle 169 was originally of the Lloyd-Creak pattern and was used throughout Cruise I as received from the maker, without modification. Deflection observations could be made only at one distance, and even these became impossible for the greater part of Cruise I (see p. 19). After the modification of the instrument (see p. 21), it was used throughout Cruise III. The adopted formulæ resulting from least-square adjustments of all available data for corrections to observed inclinations are given in Table 13.

TABLE 13.—*Inclination Corrections for Sea Dip-Circle 169.*

Number of— Suspended Needle	Number of— Deflecting Needle	Deflection Distance	Formulæ for Inclination Corrections
For observations during Cruise I and prior to Cruise III			
1			$\Delta_1 I = -$ [illegible][1]
3			$\Delta_3 I = -$ [illegible][1]
30 and 38	4	One only	$\Delta_{30} I = -$ [illegible] $-$ [illegible] $\sin I -$ [illegible] $\sin I$[2]
For observations during Cruise III			
1			$\Delta_1 I = -$ [illegible] $-$ [illegible] $\sin I -$ [illegible] $\sin I$
3			$\Delta_3 I = -$ [illegible] $-$ [illegible] $\sin I -$ [illegible] $\sin I$
30	3	Short	$\Delta_{30} I = -$ [illegible] $-$ [illegible] $\sin I -$ [illegible] $\sin I$
38	3	Short	$\Delta_{38} I = -$ [illegible] $-$ [illegible] $\sin I -$ [illegible] $\sin I$
30	3	Long	$\Delta_{30} I = -$ [illegible] $-$ [illegible] $\sin I -$ [illegible] $\sin I$
38	3	Long	$\Delta_{38} I = -$ [illegible] $-$ [illegible] $\sin I -$ [illegible] $\sin I$

[1]Corrections actually applied in original reductions of sea observations were −[illegible] for needle 1, and −[illegible] for needle 3; the mean negative correction for the two needles, actually applied, was, accordingly, [illegible] different from that finally adopted. Since, however, the induction-correction term [illegible] was determined from comparisons of [illegible] values of I with shore observations obtained with other dip circles, [illegible] with [illegible], the final correction to originally adopted values of I, corrected for ship's deviations, would be only of the order −0.3—a negligible quantity. The originally computed values of I and H are, therefore, accepted.

[2]Deflection method could not be used on Cruise I between Sept. [illegible], and Nov. 17, 1905, the deflection-distance being too short. When method could be used, the observations during Cruise I were generally made with needle 3 both direct and reversed; corrections, when necessary, to values I by 30 or by 38 or mean of 30 and 38 were taken from preceding and following observations for which the needle 3 was used in both positions.

During Cruise I inclinations on course were generally observed with both polarities of needle, and inclinations during swings were usually observed with opposite polarities during the two swings; for example, if on the port-helm swing the polarity of dip needle used was A, then, on the starboard-helm swing the polarity of same needle was B. Half polarity-differences, when necessary, were supplied with the aid of preceding and following observations with both polarities; the quantities adopted for Cruise III, from graphs based on all available data, are given in Table 14.

TABLE 14.—*Half Polarity-Differences for Sea Dip-Circle 169.*

Inclination	$\frac{1}{2}(I_A - I_B)$ for Needle No. 1	$\frac{1}{2}(I_A - I_B)$ for Needle No. 3	Inclination	$\frac{1}{2}(I_A - I_B)$ for Needle No. 1	$\frac{1}{2}(I_A - I_B)$ for Needle No. 3	Inclination	$\frac{1}{2}(I_A - I_B)$ for Needle No. 1	$\frac{1}{2}(I_A - I_B)$ for Needle No. 2
For observations during Cruise III								
[illegible]	+2.8	+2.0	+40	[illegible]	[illegible]	−20	−5.0	−4.2
[illegible]	+2.3	+0.2	+30	[illegible]	[illegible]	−30	−4.2	−3.7
[illegible]	0.2	1.0	+20	[illegible]	[illegible]	−40	−3.0	−3.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−50	−1.8	−2.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−60	−0.6	−1.0

The adopted logarithms of the total-intensity constants resulting from least-square adjustments of all available data are given in Table 15.

TABLE 15.—*Intensity Constants for Sea Dip-Circle 169.*

Number of— Suspended Needle	Number of— Deflecting Needle	Deflection Distance	No. of Weight in Loaded Needle	Logarithms of Intensity Constants
				For observations during Cruise I
4	....	....	1	C = 9.50920 during Aug. 2 to 23, 1905[1]
3D and R	4	One only	....	
4	....	....	1	C_l = 9.41866 − 0.00012 (20° − t) from Aug. 24, 1905[1]
3D	4	One only	....	C_d = 9.60033 + 0.00012 (20 − t) during Aug. 24 to Sept. 14, 1905[1]
3R	4	One only	....	C_d = 9.60238 + 0.00012 (20 − t) during Aug. 24 to Sept. 14, 1905[1]
3D	4	One only	....	C_d = 9.59564 + 0.00012 (20 − t) from Nov. 18, 1905[1]
3R	4	One only	....	C_d = 9.59821 + 0.00012 (20 − t) from Nov. 18, 1905[1]
				For observations during Cruise III; $\Delta\tau = (\tau - 1908.00)$
8	....	....	31	$C_l = 9.67097 + 0.01204\,\Delta\tau + 0.00566\,(\Delta\tau)^2 - 0.00010\,(20° - t)$
7D	8	Short	....	$C_d = 9.50033 - 0.00794\,\Delta\tau - 0.00222\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
7R	8	Short	....	$C_d = 9.50129 - 0.00794\,\Delta\tau - 0.00222\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
7D	8	Long	....	$C_d = 9.35638 - 0.00810\,\Delta\tau - 0.00379\,(\Delta\tau)^2 + 0.00010\,(20 - t)$
7R	8	Long	....	$C_d = 9.35722 - 0.00810\,\Delta\tau - 0.00379\,(\Delta\tau)^2 + 0.00010\,(20 - t)$

[1]Values of H computed by these constants were reduced to C. I. W. Standard (see p. 77) by applying a correction of $-0.00047H$.

Sea dip-circle 189.—Sea dip-circle 189, of the improved type and provided with arrangements for two deflection distances (see p. 22), was used during Cruise III, beginning at Sitka, August 1907. The adopted formulæ resulting from least-square adjustments of all available data for corrections to observed inclinations are given in Table 16.

TABLE 16.—*Inclination Corrections for Sea Dip-Circle 189.*

Number of— Suspended Needle	Number of— Deflecting Needle	Deflection Distance	Formulæ for Inclination Corrections
			′ ′ ′
5	....	....	$F\Delta I = -0.7 + 1.6 \cos I - 2.4 \sin I$
6	....	....	$F\Delta I = -1.1 + 2.1 \cos I - 1.2 \sin I$
3D	4	Short	$F\Delta I = -3.4 + 0.8 \cos I + 1.9 \sin I$
3R	4	Short	$F\Delta I = -4.0 + 1.9 \cos I + 2.9 \sin I$
3D	4	Long	$F\Delta I = -1.8 - 0.8 \cos I - 0.5 \sin I$
3R	4	Long	$F\Delta I = -1.1 - 1.8 \cos I + 0.2 \sin I$

The adopted half polarity-differences, determined from graphs based on all available data, are given in Table 17.

TABLE 17.—*Half Polarity-Differences for Sea Dip-Circle 189.*

Inclination	$\frac{1}{2}(I_A - I_B)$ for Needle No. 5	$\frac{1}{2}(I_A - I_B)$ for Needle No. 6	Inclination	$\frac{1}{2}(I_A - I_B)$ for Needle No. 5	$\frac{1}{2}(I_A - I_B)$ for Needle No. 6	Inclination	$\frac{1}{2}(I_A - I_B)$ for Needle No. 5	$\frac{1}{2}(I_A - I_B)$ for Needle No. 6
°	′	′	°	′	′	°	′	′
+80	+3.2	+ 6.8	+20	− 9.2	−18.5	−40	−6.2	−12.0
+70	+0.4	+ 1.6	+10	− 9.8	−20.2	−50	−4.2	− 7.9
+60	−2.1	− 3.4	0	−10.0	−21.0	−60	−2.0	− 3.0
+50	−4.4	− 8.0	−10	− 9.7	−20.2	−70	+0.4	+ 2.0
+40	−6.3	−12.2	−20	− 9.0	−18.3			
+30	−8.0	−15.7	−30	− 7.8	−15.6			

The adopted formulæ for the logarithms of the intensity constants, resulting from least-square adjustments of all available data, are given in Table 18.

TABLE 18.—*Intensity Constants for Sea Dip-Circle 189.*

Number of—		Deflection Distance	No. of Weight in Loaded Needle	Logarithms of Intensity Constants; $\Delta\tau = (\tau - 1908.00)$
Suspended Needle	Deflecting Needle			
4	....	....	11	$C_l = 9.38310 + 0.04056\,\Delta\tau - 0.08866\,(\Delta\tau)^2 - 0.00018\,(20° - t)$
3*D*	4	Short	....	$C_d = 9.48937 - 0.02935\,\Delta\tau + 0.05439\,(\Delta\tau)^2 + 0.00018\,(20° - t)$
3*R*	4	Short	....	$C_d = 9.49093 - 0.02935\,\Delta\tau + 0.05439\,(\Delta\tau)^2 + 0.00018\,(20° - t)$
3*D*	4	Long	....	$C_d = 9.34447 - 0.03094\,\Delta\tau + 0.04473\,(\Delta\tau)^2 + 0.00018\,(20° - t)$
3*R*	4	Long	....	$C_d = 9.34575 - 0.03094\,\Delta\tau + 0.04473\,(\Delta\tau)^2 + 0.00018\,(20° - t)$

DISCUSSION OF SEA DIP-CIRCLE CORRECTIONS.

Owing to various mechanical imperfections, unavoidable even in the best construction, values of inclination observed with the dip circle are subject to errors which can not be eliminated by multiplying observations. At any one station the correction for a particular needle and circle is found to be constant within the error of observation, except when deterioration of the pivot, *e. g.*, by wear or corrosion, causes changes, frequently quite erratic, with time. The usual practice has been to determine the correction for each needle and circle at some base-station by comparisons with standardized instruments.

For a limited range of dip it is generally found that such corrections are sufficiently close for magnetic-survey purposes, so long as the observed inclinations do not differ from the base-station value by more than 5° to 10° at the most. But when an instrument is used through a large range of inclination, as was the case on the *Galilee*, the corrections determined at one base-station can not be assumed to hold. The data obtained from the sea as well as the land work of the Department of Terrestrial Magnetism indicate that the corrections vary with inclination and total intensity, and that the variation is more pronounced for sea dip-circles than for land dip-circles. The variation is due probably in part to slight magnetic impurities in the metal of the instrument, and in part to irregularities of the pivot, different parts of which are brought in contact with the agates for different inclinations.

For inclinations observed in the plane of the magnetic meridian according to the absolute method, including reversal of polarity, the outstanding error caused by slight magnetic impurities will arise from (*a*) magnetic effects due to the fixed parts of the instrument, and from (*b*) magnetic effects due to the movable parts of the circle, viz, the arm carrying the microscopes and verniers, or an equivalent arrangement. Because of (*a*), the actual horizontal component H will be changed into $H + h + iH$, where h is the effect caused by permanent magnetization and iH that caused by induction effects from whatever source. The first effect is likely to be negligible in view of the usual careful tests for magnetic material before acceptance of an instrument, and its rejection if the presence of such material is revealed. Therefore, the entire effect, $h + iH$, arising from (*a*), may be made equal to a constant proportional part of the absolute horizontal intensity, say yH. To consider the effect arising from (*b*), resolve it into three rectangular components, one along the longitudinal axis of the movable arm, that being also parallel to the longitudinal axis of the needle, the second normal to the face of the needle, and the third perpendicular to the longitudinal axis of the arm and in the plane of inclination. Only the last component, say xF, will affect the inclination. Hence

$$H' = H + \Delta H = H + yH + xF \sin I$$

From similar consideration of the vertical intensity, Z, it follows that

$$Z' = Z + \Delta Z = Z + zZ - xF \cos I$$

By differentiation of the formula $\tan I = \frac{Z}{H}$

$$\Delta I = -\frac{\Delta H \sin I}{F} + \frac{\Delta Z \cos I}{F}$$

substituting the values of ΔH and ΔZ as above determined

$$\Delta I = -\frac{xF}{F} - \frac{yH \sin I}{F} + \frac{zZ \cos I}{F}$$

Whence

$$\Delta I = -x - \frac{y-z}{2} \sin 2I$$

But if the effects arise chiefly from induction, it is quite probable that $x = y = z$, and hence, $\Delta I = -x$, which is the correction if the error be caused entirely by a homogenous magnetic induction of the various parts of the dip circle. In general, this correction must be small for dip circles in which the movable part is relatively small.

Supposing there is a permanent magnetization of the instrument parts, and that we have h and z arising from (*a*) and f from (*b*), then similarly,

$$H' = H + \Delta H = H + h + f \sin I \qquad Z' = Z + \Delta Z = Z + z - f \cos I$$

Whence

$$\Delta I = -\frac{f}{F} - \frac{h \sin I}{F} + \frac{z \cos I}{F}$$

In general, the first two terms may be eliminated by reversal of microscopes, reversal of instrument, and by various orientations of the footscrews during observations, and only the last term would remain. Thus

$$\Delta I = \frac{z \cos I}{F}$$

That part of the error caused by irregularity of the bearing pivot-sections of the needles can be expressed by some empirical function, such as

$$\Delta I = x + y \sin I + z \cos I + \ldots$$ [1]

From the above considerations it follows that the general formula

$$F\Delta I = x + z \cos I + y \sin I$$

will express the variation of the needle-correction with changes in total intensity and inclination. The observed values of ΔI for each needle and circle, obtained from comparisons with standardized instruments at shore stations and at observatories during the *Galilee* work, were adjusted by the method of least squares in accordance with that formula. The importance of the variation in ΔI with change in F and I, particularly for the sea dip-circles, is shown by inspection of the values of coefficients x, y, and z given on pages 66–69.

Since, for even the best land dip-circles, the variations in the needle-corrections are of an order equal to or greater than the actual error of observation, the determination of a standard value for inclination at any station is a difficult question. The numerous comparisons made with earth inductors by the observers of the Department of Terrestrial Magnetism in various regions of the globe have indicated that the correction of an earth inductor on standard is subject to practically no change with variation in magnetic field. For the preliminary adjustments of the corrections of the land circles used in standardizing shore observations, reliance was, therefore, placed chiefly on the values of ΔI obtained by comparisons with earth inductors; successive and final least-square adjustments were then made, using all the shore data, improved by the preliminary adjustments. As will readily be seen, the compilations and reductions necessary for each needle and circle are long and laborious, particularly so when no field earth-inductor was available, as was the case for the *Galilee* work.[2]

---

[1] *Cf.* Chauvenet, W. Manual of spherical and practical astronomy, v. II (33).

[2] In view of the experience gained on the *Galilee* and in the land work, a field earth-inductor was added to the equipment of the *Carnegie* at the earliest possible time, viz. in September 1910.

In consequence, an attempt was made to determine the coefficients x, y, and z experimentally at Washington, by creating an artificial magnetic field, uniform over a region as great as the needle swings through, the field being regulated and maintained at a constant value during the period required to make a set of inclination observations. Such experiments were carried out by Observer P. H. Dike, who by his experience on board the *Galilee* had become familiar with the difficulties attendant upon the observation of inclination with sea dip-circles. The most feasible method to produce a desired field appeared to be by the use of coils of wire, arranged as in the Helmholtz type of tangent galvanometer—that is, two equal coaxial coils set at a distance apart equal to their radius. Two such sets of coils, each coil with a radius of 0.9 meter, with their axes at right angles, were used at each of two stations; at each station one set of coils was placed with the axis horizontal and in the magnetic meridian for controlling the horizontal component, and the other with the axis

TABLE 19.—*Needle Corrections for Sea Dip-Circle 169 during Cruise III.*

[After instrument was modified.]

[1]The computed values were obtained by means of the formulæ adopted from the least-square adjustments; those formulæ are given o

[2]Values by the station instrument were all reduced to C. I. W. Standard (see p. 77). [3]Station was at Goat Island, near San

[4]Station was at San Lorenzo Island, near Callao. [5]Deflection observations failed for the short distance at Callao.

vertical for controlling the vertical component. The current was supplied from a portable storage-battery, two separate circuits being used for the coils controlling the horizontal and vertical components. With these arrangements it was possible to observe simultaneously with a standard earth-inductor at one station and with the dip circle under test at the other station for values of inclination at regular intervals between $+88°$ and $-88°$. The results[1] of the experiment were interesting and afforded valuable data for discussion of the corrections of several of the circles used during the cruises of the *Galilee*. The method, however, was abandoned because of the great expenditure of time required, and because the results showed that practically equally good values could be arrived at by careful consideration and discussion of field comparisons, particularly so when account is taken of the changes caused by deterioration of the pivots. For exceptional instruments it was possible to secure some data for the corrections by studying critically the differences exhibited by needles among themselves for the range of inclination encountered.

Table 19 gives a condensed summary of the observed and computed data for the adopted corrections for the needles of sea dip-circle 169, which was used throughout Cruise III. This table is typical of the reductions made for each needle and circle. Inspection

[1]*Cf.* Dike, P. H. Experimental investigation of dip-needle corrections. *Terr. Mag.*, v. 14, 1909 (137–146).

shows that while the coefficients of the formulæ might now be somewhat improved, the additional labor involved in carrying out the work necessary for the slight revisions which would result is hardly warranted. As stated on page 96, values for inclination obtained from the deflected-needle observations of the total-intensity work are given less weight than those from the regular dip-needles. It is interesting to note from Table 19 the increasing uncertainty for inclinations obtained from short-distance deflections as the critical condition when deflections fail is approached. To facilitate the computations, graphs were constructed for the values of $F\Delta I$, computed from the adopted formulæ. Specimen graphs for sea dip-circle 169 are shown in Figure 2, values of $F\Delta I$ and of the inclination being indicated by ordinates and abscissæ respectively; the dash-dot line and the line of dashes only, signify, respectively, needle direct and reversed.

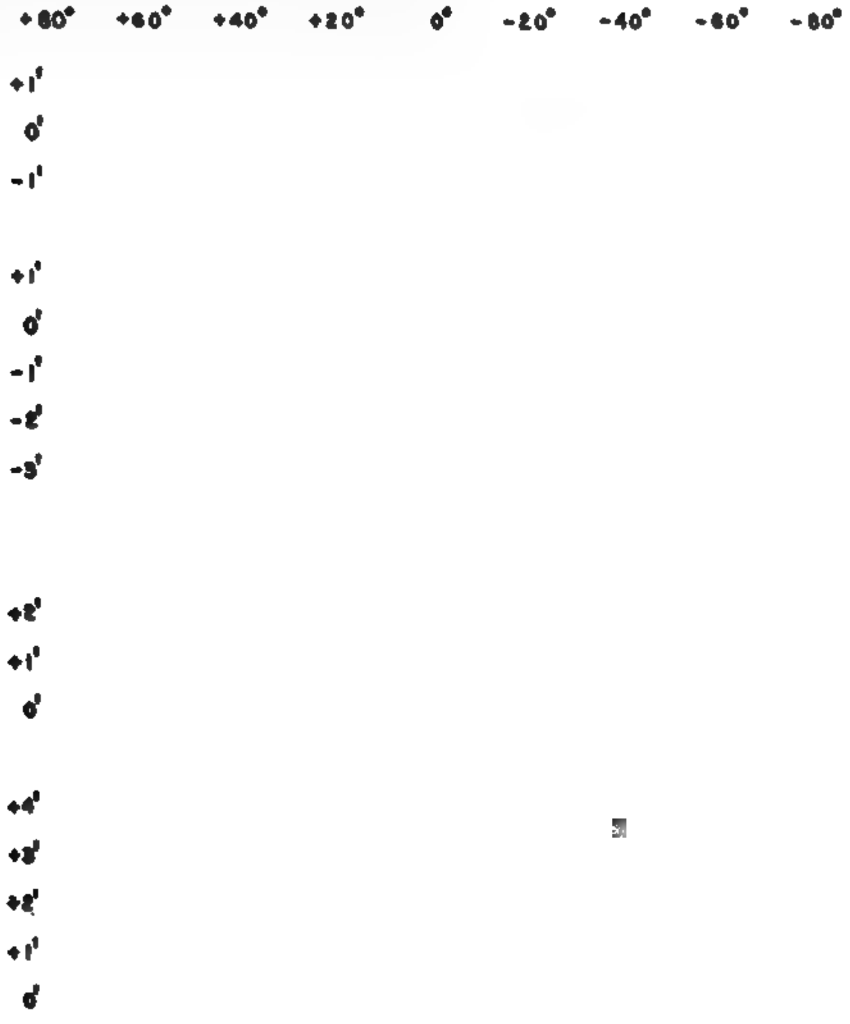


FIG. 2.—Curves showing Dip-Needle Corrections for Sea Dip-Circle 169 during Cruise III.

Table 20 gives a condensed summary of the observed and computed data for the adopted intensity-constants for needles 7 and 8, the latter loaded with weight 31, for sea dip-circle 169, which was used throughout Cruise III. That table is typical of the reductions made for each intensity-needle pair for each circle. To facilitate the computations, graphs were constructed for the values of the logarithms of each intensity-constant computed from the adopted formulæ. Figure 3 shows specimen graphs for sea dip-circle 169.

TABLE 20.—*Intensity Constants for Sea Dip-Circle 169 during Cruise III.*

[After instrument was modified.]

Station	Date	Logarithms of Intensity Constants for Needles 7 and 8[1]							Logarithm Differences (Observed minus Computed)		
		Observed Values at Mean Observed Temperature, t				Computed Values by Adopted Formulæ[2] at t					
		t	C_l	C_{4DRS}[3]	C_{4DRL}[3]	C_l	C_{4DRS}	C_{4DRL}	C_l	C_{4DRS}	C_{4DRL}
		°C.									
Washington..	1906.94	6.9	9.66359	9.50716	9.36249	9.66322	9.50802	9.36239	+0.00037	−0.00086	+0.00010
Papeete......	1907.11	32.8	9.66582	9.50574	9.36012	9.66600	9.50487	9.35967	−0.00018	+0.00087	+0.00045
Apia.........	1907.18	30.9	9.66575	9.50482	9.35901	9.66601	9.50472	9.35983	−0.00026	+0.00010	−0.00082
Yap.........	1907.29	32.3	9.66652	9.50455	9.35949	9.66650	9.50408	9.35941	+0.00002	+0.00047	+0.00008
Zikawei......	1907.37	24.1	9.66602	9.50568	9.36238	9.66604	9.50450	9.36001	−0.00002	+0.00118	+0.00237
Sitka.........	1907.56	19.0	9.66649	9.50090	9.35445	9.66668	9.50395	9.35975	−0.00019	−0.00305	−0.00530
Honolulu....	1907.67	31.8	9.66917	9.50178	9.35946	9.66880	9.50201	9.35787	+0.00037	−0.00023	+0.00159
Jaluit.......	1907.81	30.6	9.66923	9.50360	9.35893	9.66998	9.50120	9.35716	−0.00075	+0.00240	+0.00177
Christchurch .	1908.00	20.2	9.67122	9.50001	9.35605	9.67100	9.50080	9.35679	+0.00022	−0.00079	−0.00074
Callao.......	1908.20	27.3	9.67516	(4)	9.35516	9.67435	(4)	9.35430	+0.00081	(4)	+0.00086
San Francisco.	1908.40	22.7	9.67722	9.49618	9.35341	9.67696	9.49700	9.35268	+0.00026	−0.00082	+0.00073
Washington..	1908.49	34.2	9.67890	9.49571	9.34938	9.67961	9.49496	9.35048	−0.00071	+0.00075	−0.00110

[1]Needle 8 was loaded with weight 31.

[2]See Table 15, page 69, for the formulæ adopted from least-square adjustments.

[3]The mean observed values of (log C_{4D} − log C_{4R}) from the data for all the stations were −0.00084 and −0.00096 for the short and long distances respectively.

[4]Deflection observations failed for the short distance at this station, San Lorenzo Island, near Callao.

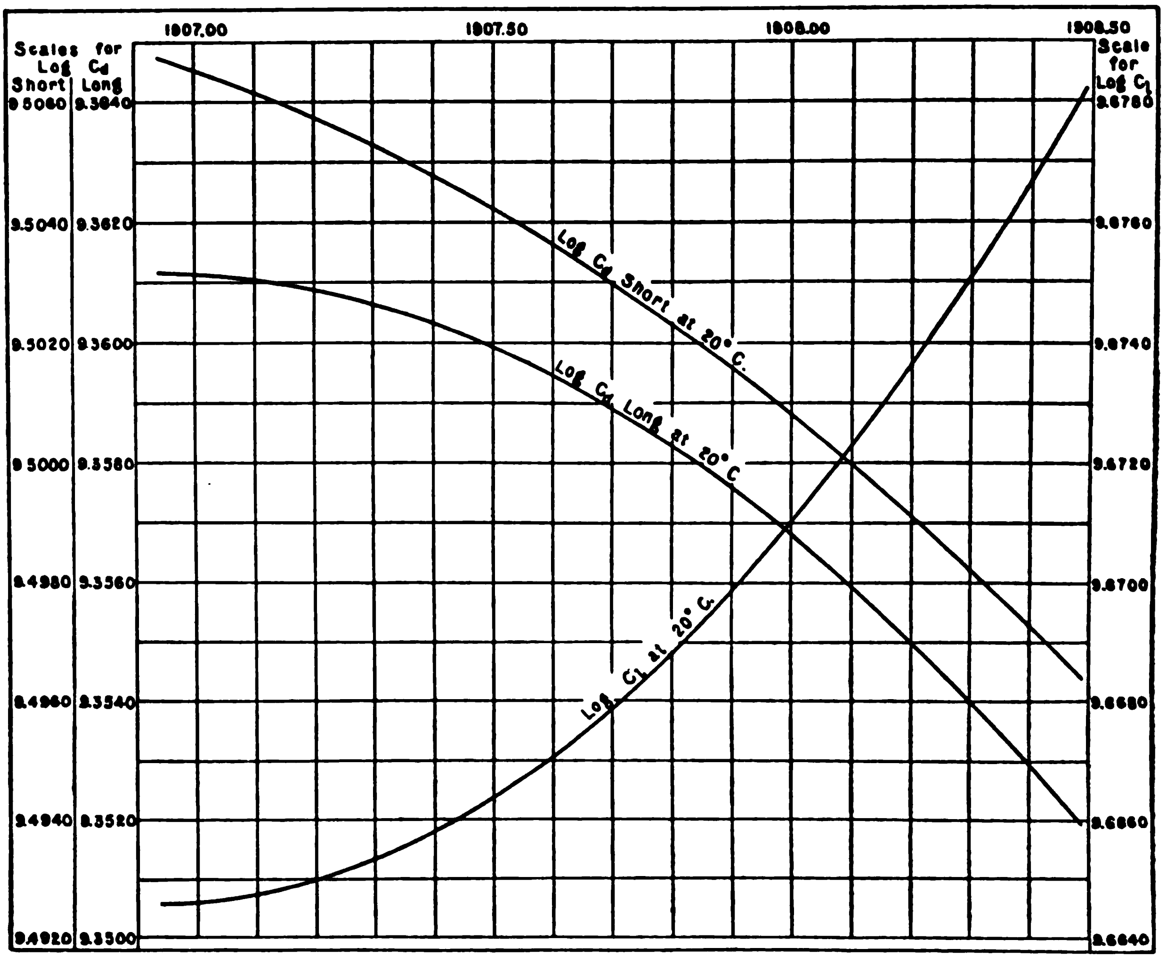


Fig. 3.—Curves showing Time-Changes in Values of Intensity Constants for Sea Dip-Circle 169 during Cruise III.

CONSTANTS AND CORRECTIONS FOR LAND INSTRUMENTS.

DESCRIPTIONS OF MAGNETOMETERS AND DIP CIRCLES.

The reduction formulæ and methods of determining constants for the land instruments, used in the *Galilee* shore-work and in the standardization of the ocean instruments during 1905–1908, were the same as those in Volume I (pp. 22–41).

The types of magnetometers used are described and illustrated in Volume I (pp. 2–7); the details respecting them and the adopted constants for the period 1905–1908 are shown in Table 21.

Magnetometer 1 was manufactured by Fauth and Company, but, before assignment to the *Galilee*, it was extensively overhauled and altered by the Department of Terrestrial Magnetism; the magnets are hollow steel bars with cross-section of octagonal periphery on the outside and circular on the inside, the long magnet being 7.2 cm. long, 0.7 cm. inside diameter and 1.2 cm. outside diameter, and the short magnet being 6.0 cm. long, 0.7 cm. inside diameter and 1.2 cm. outside diameter. Magnetometers 3 and 4 were manufactured by the Bausch and Lomb Optical Company of Rochester, New York; the magnets are hollow cylinders, the long magnets being 7.5 cm. long, 0.75 cm. inside diameter and 1.00 cm. outside diameter, and the short magnets being 3.5 cm. long, 0.61 cm. inside diameter and 0.82 cm. outside diameter. Magnetometers 30 and 36, loaned by the United States Coast and Geodetic Survey, were manufactured by T. S. Cooke and Sons of London, England; the magnets are hollow cylinders, the long magnets being 9.27 cm. long, 0.76 cm. inside diameter and 1.02 cm. outside diameter, and the short magnets being 4.33 cm. long, 0.62 cm. inside diameter and 0.83 cm. outside diameter. Phosphor-bronze-ribbon suspensions were used for all the instruments except for magnetometer 1, in which the suspension was of silk fiber.

TABLE 21.—*Details and Constants of Magnetometers Used, 1905–1908.*

[The c. g. s. system of units is used throughout this table; the value of q is given for 1° C.]

No.	Type	Diameter Horizontal Circle	Moments of Long Magnets at 20°C.		Distribution Coefficients		Induction Coefficient h	Temperature Coefficient q	Scale Value for Declination	Deflection Distances Used
			Inertia	Magnetic	P	Q				
		cm.							′	cm.
1	1 (*c*)	11.0	208	174	− 1.90[1]	....	0.0516	0.00066	2.28	30, 40
3[2]	1 (*a*)	12.5	166	673	+10.71	+1000	0.0088	0.00041	1.49	25, 27.5, 30, 35, 40
4	1 (*a*)	12.5	156	630	+14.87	− 881	0.0116	0.00035	1.49	25, 27.5, 30, 35, 40
30	2 (*b*)	13	255	882	+10.78	−1346	0.0086	0.00040	1.37	22.5, 26.2, 30, 40
36	2 (*b*)	13	248	648	+18.94	+ 511	0.0092	0.00041	1.38	30, 40

[1] This value of P is the value of P', assuming that $(1 + P'r^{-2}) = (1 + Pr^{-2} + Qr^{-4})$.
[2] Magnetometer 3 is the standard magnetometer of the Department of Terrestrial Magnetism.

The dip circles used to determine the inclination at shore stations were of the patterns which are fully described and illustrated in Volume I (pp. 7–10), viz, (*a*) the regular Kew land-pattern as made with slight variations by Dover and Casella, and (*b*) the Lloyd-Creak ship-pattern, as originally designed by Captain Ettrick W. Creak and made by Dover, and the modified type of (*b*), designated in the present volume as "sea dip-circle" (see p. 21). To determine the magnetic declination at shore stations, a compass attachment, fully described and illustrated in Volume I (p. 9), was provided for each land and sea dip-circle. (See also the present volume, pp. 20, 22, and Plate 4, Fig. 1.)

There was no earth inductor in the instrument equipment of the *Galilee*. Earth inductor 48, constructed by Schulze, fully described and illustrated in Volume I (pp. 10–11), was the standard inclination-instrument of the Department of Terrestrial Magnetism during 1905–1908.

MAGNETOMETER CORRECTIONS.

The corrections of each magnetometer on the adopted standard (see p. 77) were determined at Washington, before and after use of the instrument in the field, and also, whenever possible, in the field by means of comparisons with other magnetometers. The accuracy of the mean corrections for the land instruments is usually about 0'.2 in declination and about $0.0001H$ in horizontal intensity. The tabulated corrections are to be applied algebraically, east declination being reckoned as positive and west declination as negative; horizontal intensity is always taken as positive.

TABLE 22.—*Magnetometer Corrections on Adopted C. I. W. Standards for the Period 1905–1908.*

No. of Magnetometer	Correction to Observed		Remarks
	Declination	Horizontal Intensity	
	′		
1	−2.1	$+0.0010H$	Prior to accident of Feb. 7, 1907
1	0.0	$-0.0006H$	After accident of Feb. 7, 1907, using, however, the old constants
3	0.0	$+0.00015H$	Standard magnetometer
4	+0.7	$+0.00024H$	To June 30, 1908
4	+0.5	$+0.00020H$	Aug. 1908 to Mar. 1910, after replacement of lost deflection-bar
30	+0.2	$-0.00048H$	
36	−0.5	$+0.00113H$	Through 1906

LAND DIP-CIRCLE CORRECTIONS.

In the regular inclination observations at shore stations the polarity of the needles is invariably reversed, and, hence, the so-called balance-error caused by any eccentricity of the center of gravity of the needle is eliminated. There remains, however, the error caused by any irregularity of the figure of the pivot, and this will vary, in general, with the magnetic field. The correction-data from all comparisons at Washington, in the field, and at observatories are utilized to determine for each needle a formula expressing the variation of the correction, ΔI, with total intensity, F, and inclination, I, of the following form (see Volume I, p. 45; Volume II, p. 17, and the present Volume, pp. 71–72)

$$F\Delta I = x + z \cos I + y \sin I$$

When only a few reliable comparisons are available, or when there has been rapid deterioration of the needle-pivot, caused, *e. g.*, by slight rusting, or when the circle is used in a limited region, mean values of ΔI are adopted for all values of F and I.

The adopted dip-corrections for the land instruments are given separately for each instrument; they are applied algebraically, regarding inclination below the horizon of the north-seeking end of the needle as positive, and *vice versa*. For shore values obtained with sea dip-circles, the corrections given in Tables 10, 13, 16, on pages 66, 68, 69, were applied. The declination corrections adopted for the dip-circle compass-attachments follow the inclination corrections; the declination corrections adopted for the compass-attachments of the sea dip-circles are given on page 77.

Land dip-circle 171.—Circle 171, manufactured by Dover, was used during Cruises I, II (to May 1906), and III (from March to May 1907). The adopted inclination-corrections for the mean observed values by needle 1 and 2 for all values of I between 60° N and 60° S is 0'.0, and for all values of I between 60° N and 80° N is + 0'.5; the adopted correction for the mean of observed values by needle 5 and 6 of 172 for all values of I is + 1'.0.

The adopted correction for observed declinations by the compass attachment is + 2'.5.

Land dip-circle 178.—Circle 178, manufactured by Dover, was used during Cruises II and III. The adopted inclination-corrections are given by the formulæ

Needle 1	$F\Delta I = -1'.8 + 3'.1 \cos I - 0'.2 \sin I$
Needle 2	$F\Delta I = -1.7 + 2.3 \cos I + 0.7 \sin I$
Needle 5	$F\Delta I = -3.0 + 3.4 \cos I$
Needle 6	$F\Delta I = -1.4 + 0.9 \cos I$

The correction adopted for observed declinations by the compass attachment is $+1'.2$.

Land dip-circle 4655.—Circle 4655, manufactured by Casella and loaned by the United States Coast and Geodetic Survey, was used at one station only. The adopted inclination-correction for the mean of observed values by needles 3 and 4 is $0'.0$.

Sea dip-circles, 35, 169, and 189.—The adopted inclination-corrections for the sea and shore work during Cruises I, II, and III are given on pages 66, 68, and 69.

The corrections adopted for observed declinations by the compass attachments are:

For circle 35	$+7'.5$ when mark readings are made with peep sights, and $-9'.2$ when mark readings are made with telescope;
For circle 169	$-2'.5$ for observations in 1905; $-2'$ when mark readings are made with peep sights, and $+3'$ when mark readings are made with telescope, for observations subsequent to 1905;
For circle 189	$+8'.5$ when mark readings are made with peep sights.

MAGNETIC STANDARDS ADOPTED.

The Department's extensive intercomparisons of magnetic instruments at Washington, in the field, and at magnetic observatories in all parts of the Earth, have made it possible to refer its data to "International Magnetic Standards" within an error, in general, on the order of the observational error (see Volume II, pp. 211–278). Since the adopted constants for the sea instruments were made to depend upon the standardized data at shore stations, (see pp. 105–110), the results derived from the magnetic observations on board the *Galilee*, after being corrected for ship's deviations, are on the basis of the adopted magnetic standards.

The magnetic standards adopted for reduction to a common basis of the results contained in the present volume are the so-called "C. I. W. Standards" as defined in Volumes I (p. 42) and II (p. 16). These are: In declination, C. I. W. magnetometer 3 without correction; in horizontal intensity, C. I. W. magnetometer 3 with a correction of $+0.00015H$ applied to observed values of the horizontal intensity, H, computed by the constants given for magnetometer 3 in Table 21; in inclination, earth inductor 48 with a correction of $-0'.5$ applied to observed values of inclination. A detailed discussion of the relations between the "C. I. W. Standards" and the "International Magnetic Standards" is given in Volume II (pp. 270–278). It is shown there that the corrections of the originally selected standards are so small as to be negligible here. Accordingly, *the values of the magnetic elements, given in the Tables of Results on pages 97–110, may be regarded as based on International Magnetic Standards.*

SHIP CONSTANTS AND DEVIATION-COEFFICIENTS.

FUNDAMENTAL EQUATIONS.

Let the Earth's magnetic force, acting on a magnetic needle at a given position on board ship, be resolved into three rectangular components, two of which are horizontal and one is vertical, viz: X, in the direction of the fore-and-aft line towards the ship's head; Y, towards the starboard side; and Z, towards the keel; X and Y are the two horizontal components, and Z is the vertical component. Furthermore, let X', Y', and Z' represent the same components resulting from the combined action of the Earth's magnetic field and that of the ship. Then the well-known, fundamental equations in the mathematical theory of ship deviations, first given by Poisson in 1824, are

$$X' = X + aX + bY + cZ + P \tag{1}$$

$$Y' = Y + dX + eY + fZ + Q \tag{2}$$

$$Z' = Z + gX + hY + kZ + R \tag{3}$$

The parameters $a, b, c, d, e, f, g, h, k$ depend on the amount, arrangement, and inductive capacity of the soft iron of the ship. P, Q, R are parameters depending on the amount, arrangement, and permanent or subpermanent magnetism of the hard iron of the ship.

The above formulæ assume that the ship's magnetic field results partly from the permanent magnetism of hard iron and steel and partly from the transient, induced magnetism of soft iron, the latter supposed to be directly proportional to the intensity of the inducing force. It is, furthermore, assumed that the length of the magnetic needle is infinitesimally small in comparison with the distance to the nearest iron aboard the ship. These assumptions may be regarded as amply fulfilled on the *Galilee*, in view of the smallness of the parameters for this vessel. If the vessel is not on even keel, corrective terms enter, which for the *Galilee* under the usual observing conditions could be regarded as negligible.

Deviation Formulæ.

Let the so-called deviation-coefficients for the magnetic elements, declination (D), inclination (I), horizontal intensity (H), and vertical intensity (Z), be

For D: A_d, B_d, C_d, D_d, E_d
For I: A_i, B_i, C_i, D_i, E_i
For H: A_h, B_h, C_h, D_h, E_h
For Z: A_z, B_z, C_z

Then the deviation formulæ for D, I, H, and Z, after various transformations and approximations, may be written as follows:[1]

$$D' - D = \delta D = A_d + B_d \sin\zeta + C_d \cos\zeta + D_d \sin 2\zeta + E_d \cos 2\zeta \tag{4}$$

$$I' - I = \delta I = A_i + B_i \cos\zeta + C_i \sin\zeta + D_i \cos 2\zeta + E_i \sin 2\zeta \tag{5}$$

$$H' - H = \delta H = A_h + B_h \cos\zeta + C_h \sin\zeta + D_h \cos 2\zeta + E_h \sin 2\zeta \tag{6}$$

$$Z' - Z = \delta Z = A_z + B_z \cos\zeta + C_z \sin\zeta \tag{7}$$

[1]The reader may be referred to the following treatises, for example: Admiralty Manual for the Deviations of the Compass, London, 1912, pp. 96–99; F. Bidlingmaier, Magnetische Beobachtungen an Bord, pp. 469–478 of Neumayer's Anleitung zu wissenschaftlichen Beobachtungen auf Reisen, Hannover, 1905; E. Mascart, Traité de Magnétisme Terrestre, pp. 402–436, Paris, 1900.

D', I', H', Z' are, respectively, the observed ship values of the declination, inclination, horizontal intensity, and vertical intensity; D, I, H, Z are the true, or undisturbed, values—those which would be observed if the ship were wholly non-magnetic.

The deviation-correction is the quantity to be applied to the magnetic element observed aboard ship to obtain the true or undisturbed value. It is of opposite sign to the deviation; thus, *e. g.*, $D = D' - \delta D$; etc.

In the above formulæ ζ, because of the smallness of the deviation-effect on the compass aboard the *Galilee*, may be taken directly as the ship's indicated magnetic course, or as the indicated magnetic azimuth of the ship's head, measured continuously from the magnetic north through east.

Let $\lambda = H'/H$, $\mu = Z'/Z$, and let the so-called "exact deviation-coefficients" be indicated by primes, *e. g.*, A'_d, B'_d, etc.; then the relations existing between the parameters and the deviation-coefficients are:

For Declination

$$\lambda = 1 + \frac{1}{2}(a + e) \tag{8}$$

$$A'_d = \sin A_d = \frac{1}{\lambda}\left(\frac{d-b}{2}\right) \tag{9}$$

$$B'_d = \sin B_d = \frac{1}{\lambda}\left(c \tan I + \frac{P}{H}\right) \tag{10}$$

$$C'_d = \sin C_d = \frac{1}{\lambda}\left(f \tan I + \frac{Q}{H}\right) \tag{11}$$

$$D'_d = \sin D_d = \frac{1}{\lambda}\left(\frac{a-e}{2}\right) \tag{12}$$

$$E'_d = \sin E_d = \frac{1}{\lambda}\left(\frac{d+b}{2}\right) \tag{13}$$

For Inclination

$$A'_i = \sin A_i = \frac{1}{2}(\lambda - \mu)\sin 2I = \frac{1}{2}\left(\lambda - k - 1 - \frac{R}{Z}\right)\sin 2I \tag{14}$$

$$B'_i = \sin B_i = \frac{1}{2}(\lambda B'_d - g \cot I)\sin 2I = \frac{1}{2}(c-g) - \frac{1}{2}(c+g)\cos 2I + \frac{1}{2}\frac{P}{H}\sin 2I \tag{15}$$

$$C'_i = \sin C_i = \frac{1}{2}(h \cot I - \lambda C'_d)\sin 2I = \frac{1}{2}(h-f) + \frac{1}{2}(h+f)\cos 2I - \frac{1}{2}\frac{Q}{H}\sin 2I \tag{16}$$

$$D'_i = \sin D_i = +\frac{1}{2}\lambda D'_d \sin 2I = \frac{1}{2}\left(\frac{a-e}{2}\right)\sin 2I \tag{17}$$

$$E'_i = \sin E_i = -\frac{1}{2}\lambda E'_d \sin 2I = -\frac{1}{2}\left(\frac{d+b}{2}\right)\sin 2I \tag{18}$$

For Horizontal Intensity

$$A_h = \frac{H}{2}(a+e) = H(\lambda - 1) \tag{19}$$

$$B_h = cH \tan I + P = \lambda H \cdot B'_d = \lambda H \cdot \sin B_d \tag{20}$$

$$C_h = -fH \tan I - Q = -\lambda H \cdot C'_d = -\lambda H - \sin C_d \tag{21}$$

$$D_h = \frac{H}{2}(a - e) = \lambda H \cdot D'_d = \lambda H \cdot \sin D_d \tag{22}$$

$$E_h = -\frac{H}{2}(d + b) = -\lambda H \cdot E'_d = -\lambda H \sin E_d \tag{23}$$

For Vertical Intensity

$$A_z = kZ + R = Z(\mu - 1) \tag{24}$$

$$B_z = gZ \cot I \tag{25}$$

$$C_z = -hZ \cot I \tag{26}$$

$$\mu = k + 1 + \frac{R}{Z} \tag{27}$$

From the usual observations at the positions (see Fig. 1, p. 27, and Plate 2, Fig. 1) of the various instruments on the *Galilee's* observing-bridge, we may derive combinations of the quantities above mentioned. Thus

For Standard-Compass Position (Declination)

$$\frac{1}{\lambda}\left(\frac{a-e}{2}\right),\ \frac{b}{\lambda},\ \frac{c}{\lambda},\ \frac{d}{\lambda},\ \frac{f}{\lambda},\ \frac{P}{\lambda},\ \text{and}\ \frac{Q}{\lambda}$$

For Sea-Deflector Position (Declination and Horizontal Intensity)

λ, a, b, c, d, e, f, P, and Q

For Sea-Dip-Circle Position (Inclination and Total Intensity)

λ, a, c, e, f, g, h, k, P, Q, and R

DEVIATION-COEFFICIENTS FOR CRUISES I, II, AND III.

Forms 23, 23*a*, pages 36 and 39, give, respectively, specimens of derivation of deviation-coefficients for declination and horizontal intensity. Those for inclination are derived in a similar manner (see pp. 43-45). The values of the coefficients, resulting from the various swings and for the three magnetic elements, D, I, H, are given separately for each cruise in Tables 23–28, pages 81–85. The column-headings and explanatory remarks will make clear the entries and conditions under which the quantities were derived. The same general designations for instruments, as given on pages 28–32 and 94 have been used in these tables. For interpretation of symbols appearing in columns of "Remarks," see page 95. The columns, "Headings," give the number of headings on port swing (p) and the number on the starboard swing (s).

The probable-error columns give the probable errors of an observed deviation on a single heading; they have been computed as shown in Forms 23 and 23*a*, pages 36 and 39. The intensity unit used for the deviation-coefficients and probable errors, which appear in Tables 24, 26, and 28, is the fourth decimal C. G. S. In these same tables, the letters S, L, appearing in the columns "Dip Circle" and "Deflector (Defl'r)," stand, respectively, for short deflecting-distance and for long deflecting-distance.

On the various cruises, the *Galilee* was swung about every fifth or sixth day, the average distance between swing-stations being somewhat over 600 miles. An inspection of the quantities in the probable-error columns shows a steady improvement in accuracy of observation for all the magnetic elements as the work advanced and the various difficulties caused by ship conditions and imperfection of sea instruments were more or less successfully overcome. Only occasionally did the probable error reach a magnitude, because of conditions encountered, such as to warrant either total rejection of the results of the swing, or giving them diminished weight in the final adjustments, explained in the next paragraph.

TABLE 23.—*Declination and Inclination Deviation-Coefficients and Details regarding Swings of the Galilee, 1905.*

*Local disturbance.
[1]The swings at San Francisco, on each of the 3 days, were made on 16 equidistant headings, with both helms; as the methods of observation were more or less experimental, only the mean results of the 3 days are given.
[2]Before the swing on August 23 at San Diego, made between land stations I and III, iron bolts in foremast were replaced by brass ones. Swung at anchor; tug about 40 yards off the stern.
[3]After additional alterations of vessel were made (see p. 131), and instruments were rearranged on observing bridge (see Fig. 1, *B*, p. 27). Swung at anchor; tug about 40 yards off the stern.
[4]The compass and dip-circle results for this swing were not used.
[5]December 4 and 6 the iron-fastened dinghy was inadvertently left lying across main hatch, directly under the observing bridge.
[6]Deflecting magnet of sea deflector in place on bridge. [7]Deflecting magnet of sea deflector removed from bridge.

TABLE 24.—*Horizontal-Intensity Deviation-Coefficients[1] and Details regarding Swings of the Galilee, 1905.*

*Local disturbance. [1]Intensity deviation-coefficients and probable errors are expressed in units of the fourth decimal c. g. s.
[2]Owing to the limited number of headings, but small weight is to be given these values. [3]Vessel rolling considerably.
[4]Ship on even keel before the wind, except for rolling.

CRUISE II, FEBRUARY TO OCTOBER 1906.

TABLE 25.—*Declination and Inclination Deviation-Coefficients and Details regarding Swings of the Galilee, 1906.*

[1]Two starboard swings; one, 8 headings; other, 6

[2]Two starboard swings; both 8 headings.

[3]Two port swings; both 8 headings.

[4]Two port swings; one, 6 headings; other, 8.

[5]The declination results were not used, the swing being but a partial one.

[6]Before accident.

[7]After accident.

CRUISE II, FEBRUARY TO OCTOBER 1906.

TABLE 26.—*Horizontal-Intensity Deviation-Coefficients*[1] *and Details regarding Swings of the Galilee, 1906.*

[1]Intensity deviation-coefficients and probable errors are expressed in units of fourth decimal c. g. s.

[2]Two starboard swings of 8 headings each.

[3]For D. C. work, 8 p, 8 s.

[4]For D. C. work, 6 p, 6 s.

[5]For D. C. work, 8 p, 8 s.

[6]Two port swings: For D. C. work, 6 headings, first swing, and 8, second swing; for Defl'r work, 5 headings, first swing, and 8, second swing; also for D. C. work, 8 headings, starboard swing.

[7]For D. C. work, 0 p, 8 s.

[8]For D. C. work, 0 p, 8 s.

[9]For D. C. work, 8 p, 8 s.

[10]For D. C. work, 6 p, 6 s.

[11]For D. C. work, 0 p, 8 s.

[12]For D. C. work, 0 p, 6 s.

[13]For D. C. work, 8 p, 8 s.

TABLE 27.—*Declination and Inclination Deviation-Coefficients and Details regarding Swings of the Galilee, 1906–1908.*

[illegible]

*Local disturbance.

CRUISE III, DECEMBER 1906 TO MAY 1908.

TABLE 28.—*Horizontal-Intensity Deviation-Coefficients*[1] *and Details regarding Swings of the Galilee, 1906–1908.*

[1]Intensity deviation-coefficients and probable errors are expressed in units of fourth decimal c. g. s.

Headings for D. C. Work | *Headings for D. C. Work* | *Headings for D. C. Work* | *Headings for D. C. Work* | *Headings for D. C. Work* | *Headings for D. C. Work*

ADJUSTMENT OF DEVIATION-COEFFICIENTS AND DERIVATION OF PARAMETERS.

The adjustments of all observed coefficients obtained from the swings for each magnetic element were made after dividing the coefficients into groups, each group being adjusted separately. Group 1 of Cruise I was experimental. Parameters were not used to compute deviations for this group. Group 2 includes the rest of this short cruise. The coefficients for Cruises II and III were grouped from consecutive portions of a cruise during which the vessel's course lay in the same general direction. This method of grouping was adopted on the assumption that the ship's parameters are liable to alterations as the ship changes from one course, whereon she has experienced continued buffeting, to a widely different one, where she again experiences continued buffeting by the sea.

The arrangement of the groupings and the periods of time to which the coefficients and parameters of each group apply are shown in Table 29.

TABLE 29.—*Grouping and Periods of Time for Deviation-Coefficients.*

Cruise	Group	Period of Time Corresponding to each Group	Portion of Cruise Covered
Galilee I	1	Aug. 2, 1905, to Aug. 23, 1905	San Francisco to San Diego
Galilee I	2	Aug. 24, 1905, to Dec. 13, 1905	San Diego to San Diego
Galilee II	1	Feb. 14, 1906, to May 18, 1906	San Diego to Fiji Islands
Galilee II	2	May 18, 1906, to Aug. 21, 1906	Fiji Islands to Yokohama
Galilee II	3	Sept. 6, 1906, to Oct. 22, 1906	Yokohama to San Diego
Galilee III	1	Dec. 18, 1906, to Feb. 5, 1907	San Diego to Papeete, Tahiti
Galilee III	2	Feb. 4, 1907, to June 1, 1907	Papeete, Tahiti, to Yangtse R.
Galilee III	3	May 31, 1907, to July 19, 1907	Yangtse R. to Sitka
Galilee III	4	July 17, 1907, to Jan. 2, 1908	Sitka to Port Lyttelton
Galilee III	5	Jan. 2, 1908, to Apr. 4, 1908	Port Lyttelton to Callao
Galilee III	6	Apr. 4, 1908, to May 28, 1908	Callao to San Francisco

The overlappings of dates in the above groups indicate that the same coefficients have occasionally been included in each adjustment of two adjacent groups.

For convenience in making the least-square adjustment of the coefficients and in computing coefficients from the parameters determined by this least-square adjustment for any place at which the deviation corrections are required, the expressions for the coefficients have been modified as follows:

Declination.—Equations (8) to (13), page 79, are simplified by expressing the quantities in degrees, making

$$x = \frac{c}{\lambda \sin 1^\circ} \qquad y = \frac{P}{\lambda \sin 1^\circ} \qquad x' = \frac{f}{\lambda \sin 1^\circ} \qquad y' = \frac{Q}{\lambda \sin 1^\circ}$$

and dividing the expressions for A_d, D_d, and E_d by sin 1°. Then

$$A_d = \frac{1}{\lambda} \cdot \frac{d-b}{2 \sin 1^\circ} \tag{27}$$

$$B_d = x \tan I + y \frac{1}{H} \tag{28}$$

$$C_d = x' \tan I + y' \frac{1}{H} \tag{29}$$

$$D_d = \frac{1}{\lambda} \cdot \frac{a-e}{2 \sin 1^\circ} \tag{30}$$

$$E_d = \frac{1}{\lambda} \cdot \frac{d+b}{2 \sin 1^\circ} \tag{31}$$

The numerical values of the coefficients B_d and C_d, which are functions of the horizontal intensity and inclination, may readily be computed from the values of x, y, x', and y' given for the period of time covered by each group-adjustment in Table 30 containing the declination deviation-constants and parameters for standard-compass position. The numerical

values of A_d, D_d, and E_d, which are constant according to theory, will also be found in this table. The parameters $\frac{1}{\lambda}\left(\frac{a-e}{2}\right)$, $\frac{b}{\lambda}$, $\frac{c}{\lambda}$, $\frac{d}{\lambda}$, $\frac{f}{\lambda}$, $\frac{P}{\lambda}$, and $\frac{Q}{\lambda}$, derived from the values of x, y, x', and y', A_d, D_d, and E_d, are included in the table merely for the purpose of comparing their values as determined from the different groups, or for comparing them with those of other ships.

TABLE 30.—*Declination Deviation-Constants and Parameters for Standard-Compass Position.*

Cruise	Group	A_d	D_d	E_d	x	y	x'	y'	$\frac{1}{\lambda}\left(\frac{a-e}{2}\right)$	$\frac{b}{\lambda}$	$\frac{c}{\lambda}$	$\frac{d}{\lambda}$	$\frac{f}{\lambda}$	$\frac{P}{\lambda}$	$\frac{Q}{\lambda}$
		°	°	°	°	°	°	°						c. g. s.	c. g. s.
I	2	.00	+.07	−.06	−.0672	+.0765	+.1027	−.0427	+.0012	−.0010	−.0012	−.0010	+.0018	+.0013	−.0007
II	1	.00	+.10	−.01	+.0428	−.0494	+.0116	−.0062	+.0017	−.0002	+.0007	−.0002	+.0002	−.0009	−.0001
	2		+.03	−.03	+.0650	−.0254	−.0345	−.0224	+.0005	−.0005	+.0011	−.0005	−.0006	−.0004	−.0004
	3		+.07	.00	+.0072	+.0148	−.3408	+.1049	+.0012	.0000	+.0001	.0000	−.0059	+.0003	+.0018
III	1	−.03	+.07	−.02	−.0184	+.0009	+.0501	−.0298	+.0012	+.0002	−.0003	−.0009	+.0009	.0000	−.0005
	2		+.13	−.01	+.2535	−.0030	−.1012	−.0353	+.0023	+.0003	+.0044	−.0007	−.0018	−.0001	−.0006
	3		+.14	−.01	−.1060	+.0671	+.1342	−.0881	+.0024	+.0003	−.0018	−.0007	+.0023	+.0012	−.0015
	4		+.11	−.04	+.0522	−.0207	−.0400	+.0172	+.0019	−.0002	+.0009	−.0012	−.0007	−.0004	+.0003
	5		+.14	.00	+.1588	−.0823	−.1761	−.0300	+.0024	+.0005	+.0028	−.0005	−.0031	−.0006	−.0005
	6		+.10	.00	−.1123	+.0132	+.0563	−.0713	+.0017	+.0005	−.0020	−.0005	+.0010	+.0002	−.0012

TABLE 31.—*Inclination Deviation-Constants and Parameters for Sea-Dip-Circle Position.*

Cruise	Group	x	y	z	x'	y'	z'	x''	x'''	c	f	g	h	P	Q
		°	°	°	°	°	°	°	°					c. g. s.	c. g. s.
I	2	−0.390	+.350	+.183	−1.458	+.946	+.642	−.099	+.128	−.0129	+.0420	+.0007	−.0090	+.0064	−.0224
II	1	+0.023	−.037	+.014	+0.029	−.544	−.026	−.052	.000	+.0010	−.0100	+.0002	−.0090	+.0005	+.0009
	2	+0.057	−.011	+.029	−0.209	−.009	−.032	−.037	−.003	+.0012	+.0035	−.0008	−.0038	+.0010	+.0011
	3	−0.582	−.097	+.206	−1.937	+.493	+.562	−.054	+.009	−.0085	+.0424	+.0118	−.0252	+.0072	−.0196
III	1	+0.040	−.003	−.006	−0.089	−.023	.000	−.052	+.009	+.0008	+.0012	−.0006	−.0020	−.0002	.0000
	2	+0.014	+.077	+.017	+0.352	−.653	−.014	−.026	+.017	−.0011	−.0176	−.0016	−.0052	+.0006	+.0005
	3	+1.384	+.289	−.321	+1.576	−.232	−.501	−.040	+.032	+.0191	−.0316	−.0292	+.0235	−.0112	+.0175
	4	+0.089	+.069	+.029	−0.069	−.138	−.011	−.014	+.026	+.0003	−.0012	−.0028	−.0036	+.0010	+.0004
	5	−0.582	+.578	−.327	−0.447	+.665	−.286	−.026	−.009	−.0202	+.0194	+.0002	+.0038	−.0114	+.0100
	6	+0.166	+.149	+.066	+0.390	+.020	+.014	−.100	+.014	+.0003	−.0064	−.0055	+.0072	+.0023	−.0005

The computation of the deviations is greatly expedited by a tabular arrangement in which all the values of any columns may be entered at one time, if desired. For specimen computation, see page 92.

Inclination.—Equations (14) to (18), page 79, are simplified by expressing the quantities in degrees and by making

$$x=\frac{c-g}{2\sin 1^\circ}\qquad y=-\frac{c+g}{2\sin 1^\circ}\qquad z=\frac{P}{2\sin 1^\circ}\qquad x'=\frac{h-f}{\cancel{4}\sin 1^\circ}$$

2

$$y'=\frac{h+f}{2\sin 1^\circ}\qquad z'=-\frac{Q}{2\sin 1^\circ}\qquad x''=\frac{a-e}{\cancel{2}\sin 1^\circ}\qquad x'''=\frac{d+b}{4\sin 1^\circ}$$

4

Then we have

$$A_i=\frac{\lambda-\mu}{2\sin 1^\circ}\sin 2I=\frac{\lambda-k-1}{2\sin 1^\circ}\sin 2I-\frac{R}{\sin 1^\circ}\frac{1}{H}\cos^2 I \tag{32}$$

$$B_i=x+y\cos 2I+z\frac{\sin 2I}{H} \tag{33}$$

$$C_i=x'+y'\cos 2I+z'\frac{\sin 2I}{H} \tag{34}$$

$$D_i=x''\sin 2I \tag{35}$$

$$-E_i=x'''\sin 2I \tag{36}$$

The values of x, y, z, x', y', z', x'', x''', and the parameters c, f, g, h, P, and Q, for the period of time covered by each group-adjustment, are given in Table 31.

The computation of inclination-deviations is shown in Table 38, page 92.

Horizontal Intensity.—The least-square adjustment of the coefficients and the computations of the coefficients and deviations are more conveniently made if the unit of H is so taken as to avoid many decimals. This is accomplished by expressing H in units of the fourth decimal place C. G. S. If also $x' = \dfrac{a-e}{2}$, and $x'' = \dfrac{d+b}{2}$, (19) to (23) become

$$A_h \cdot 10^4 = H \cdot 10^4 \cdot (\lambda - 1) \qquad D_h \cdot 10^4 = H \cdot 10^4 \cdot x'$$
$$B_h \cdot 10^4 = c \cdot H \cdot 10^4 \cdot \tan I + P \cdot 10^4 \qquad E_h \cdot 10^4 = -H \cdot 10^4 \cdot x''$$
$$C_h \cdot 10^4 = -f \cdot H \cdot 10^4 \cdot \tan I - Q \cdot 10^4$$

The numerical values of B_h and C_h, expressed in units of the fourth decimal place C. G. S., may readily be computed from the values given for the period of time covered by each group-adjustment in Tables 32 to 34, which give the deviation-constants and parameters for the positions of sea deflector and of sea dip-circle. For the position of sea dip-circle there are two sets of values: one is derived from observations of the horizontal intensity by deflections, and the other is derived from the loaded-needle observations. The parameters λ, a, b, c, d, e, f, P, and Q are given in Table 32 for the sea-deflector position. For the dip-circle position, values of the parameters already appear in Table 31, which were deduced from the inclination observations. Tables 33 and 34 contain additional values for the same parameters, except g and h, as also for λ, a, e, and k.

TABLE 32.—*Horizontal-Intensity Deviation-Constants and Parameters for Sea-Deflector Position.*

Cruise	Group	A_g	x'	x''	λ	a	b	c	d	e	f	P	Q
		°										c. g. s.	c. g. s.
I	2	......	−.00225	+.00108	1.00318	+.00093	....	+.00606	....	+.00543	−.00137	+.0015	−.0001
II	1	......	−.00308	+.00086		−.00554	....	+.00361	....	+.00062	−.00227	+.0010	+.0007
	2	......	−.00271	+.00160	0.99754	−.00517	....	+.00070	....	+.00025	+.00036	+.0012	−.0002
	3	......	−.00322	+.00134		−.00568	....	+.01069	....	+.00076	+.00404	−.0027	−.0014
III	1	......	−.00150	+.00066		−.00253	....	+.00138	....	+.00047	−.00020	+.0009	.0000
	2	......	−.00139	+.00039		−.00242	....	+.00103	....	+.00036	−.00019	+.0007	−.0001
	3	......	−.00078	+.00122	0.99897	−.00181	....	+.00499	....	−.00025	−.00021	−.0006	−.0005
	4		+.00094	+.00064		−.00009	−.00006	+.00294	+.00134	−.00197	+.00011	+.0003	−.0006
	5	+.04	+.00279	+.00088		+.00176	+.00018	+.00147	+.00158	−.00382	+.00139	−.0009	+.0001
	6		+.00450	+.00102		+.00347	+.00032	+.00043	+.00172	−.00553	−.00017	−.0004	−.0004

TABLE 33.—*Horizontal-Intensity Deviation-Constants and Parameters for Sea-Dip-Circle Position (Loaded-Dip Observations)*

Cruise	Group	x'	x''	λ	a	c	e	f	k	P	Q
										c. g. s.	c. g. s.
I[1]	2	+.00439	−.00303	1.00122	+.00561	+.00068	−.00317	−.0215	−.0056	−.0022	+.0028
II	1	+.00181	+.00041		−.00014	−.00065	−.00376	−.00146		−.0006	+.0009
	2	+.00208	+.00002	0.99805	+.00013	−.00061	−.00403	−.00634	−.0088	−.0006	+.0017
	3	+.00087	+.00054		−.00108	+.01294	−.00282	−.04750		−.0064	+.0163
III	1	+.00026	+.00102		+.00076	+.00026	+.00024	+.00010		−.0005	−.0002
	2	−.00047	+.00118		+.00003	−.00562	+.00097	+.00139		−.0007	.0000
	3	+.00113	−.00053	1.00050	+.00163	−.00976	−.00063	−.00630	−.0063	+.0010	+.0004
	4	+.00155	+.00010		+.00205	−.00649	−.00105	−.00701		−.0011	−.0001
	5	−.00389	−.00289		−.00339	−.02128	+.00439	+.03148		+.0004	−.0016
	6	−.00316	+.00080		−.00266	−.01279	+.00366	+.02125		+.0032	−.0019

[1]The deviation-corrections were not computed from these parameters, but were taken from a deviation-table based on the analysis of each swing.

One value of R has been deduced for the sea-dip-circle position which applies to the three cruises. It is $R = -0.0010$ C. G. S.

TABLE 34.—*Horizontal-Intensity Deviation-Constants and Parameters for Sea-Dip-Circle Position (Deflection Observations).*[1]

Cruise	Group	x'	x''	λ	a	c	e	f	k	P	Q
										c. g. s.	*c. g. s.*
II	1	+.00147	−.00062		+.00066	−.00061	−.00228	+.00187		−.0009	−.0005
	2	+.00174	+.00047	0.99919	+.00093	−.00068	−.00255	−.00438	−.0076	−.0009	−.0004
	3	+.00134	+.00046		+.00053	+.00834	−.00215	−.00756		−.0052	+.0010
III	1	+.00104	−.00002		−.00513	+.00044	−.00721	−.00115		−.0008	−.0003
	2	+.00141	+.00009		−.00476	−.00207	−.00758	+.00009		−.0009	−.0005
	3	+.00224	−.00086	0.99383	−.00393	−.00285	−.00841	−.00180	−.0130	−.0011	+.0001
	4	+.00131	−.00069		−.00486	−.00303	−.00748	−.00245		−.0013	−.0007
	5	+.00150	−.00001		−.00467	−.00531	−.00767	+.00244		+.0004	−.0006
	6	+.00199	−.00036		−.00418	−.00389	−.00816	+.00618		−.0004	+.0001

A specimen computation of the horizontal-intensity deviations for April 14, 1908, at the sea-deflector position, will be found in Table 39, page 92.

GENERAL REMARKS.

On comparing the values of the parameters, group by group, for any one instrument-position, changes will be found for which no complete explanation can be given. They may be ascribed partly to dynamic effects, partly to real changes that have occurred in the magnetism of the ship because of one course having been held approximately throughout the periods of the groups.

Some of the parameters at the sea-dip-circle position are deduced both from observations of inclination and horizontal intensity. The differences between these two determinations may be referred to instrumental deviations partly, and partly to dynamic effects.

The deviation-equations for sea deflectors 1 and 2 show, very clearly, the existence of instrumental deviations. The latter may be caused by small impurities in the metal parts or by lack of exact centering of the card in the compasses which had to be used with these deflectors. In view of their small magnitude, they may always be treated as part of the ship deviations.

STARBOARD ANGLE AT THE THREE POSITIONS OF THE GALILEE INSTRUMENTS.

The starboard angle, α, is defined, in treatises on magnetism of ships, as the direction of the resultant of the forces producing semicircular deviation in the compass. It is determined from the equation

$$\tan \alpha = C'_s / B'_s \tag{37}$$

It lies in the horizontal plane passing through the instrument, and is reckoned positive from the ship's head around by starboard. Expressing C_s' and B_s' in terms of parameters, the above equation becomes

$$\tan \alpha = \frac{\frac{1}{\lambda}\left(f \tan I + \frac{Q}{H}\right)}{\frac{1}{\lambda}\left(c \tan I + \frac{P}{H}\right)} = \frac{fZ+Q}{cZ+P} = \frac{fZ}{cZ+P} + \frac{Q}{cZ+P} \tag{38}$$

From this equation it is evident that if f and c are not zero, the starboard angle, α, is not constant as the vessel sails around the world.

[1]On the greater portion of Cruise I, the deflection method was not available (see pp. 21–22). The deviation-corrections were taken from a table based on the analysis of each separate swing.

If the value of the starboard angle is represented by a', when f and c are both zero, then

$$\tan a' = \frac{Q}{P} \tag{39}$$

which determines the direction of the resultant of the forces of permanent magnetism that produce semicircular deviation. If the value of this resultant be ρ', we have

$$\rho' = \sqrt{P^2+Q^2} \tag{40}$$

Similarly, if the starboard angle is represented by a'', when P and Q are both zero, then

$$\tan a'' = \frac{fZ}{cZ} = \frac{f}{c} \tag{41}$$

which determines, under the conditions stated, the direction of the resultant of the forces of induced magnetism that produce semicircular deviation. Representing by ρ'' the value of this resultant

$$\rho'' = \sqrt{(c\,Z)^2+(f\,Z)^2} \tag{42}$$

The angles a' and a'', and the resultant ρ', are theoretically constant for the same vessel in all parts of the world, but the values of the resultant ρ'' and the starboard angle a depend upon the vertical intensity, Z, of the Earth's magnetic field.

The angle a' is completely determined by the values and the signs of P and Q. The angle a'', however, is not so completely determined from equation (41), since a positive value of c may result from soft iron forward of and below the instrument or from soft iron abaft the instrument and above it. Moreover, a positive value of f may result from the presence of soft iron to starboard of the instrument and below it or from the presence of soft iron to port and above the instrument.

TABLE 35.—*Values of the Angles a' and a'' and of the Resultant of the Components of Permanent Magnetism for the Galilee.*

Instrument Position	Cruise I, 1905[1]			Cruise II, 1906			Cruise III, 1906–08		
	a'	a''	ρ'	a'	a''	ρ'	a'	a''	ρ'
	°	°	c.g.s.	°	°	c.g.s.	°	°	c.g.s.
Deflector.............	356	347	.002	240	8	.000	270	3	.000
Standard Compass.....	332	124	.002	128	287	.001	274	341	.001
Dip Circle............	282	121	.010	167	293	.001	133	174	.002

On the *Galilee* certain assumptions are admissible which remove the ambiguity of the algebraic signs of c and f. The rigging was changed from iron to hemp. The magnets of the instruments were about 16 feet above the deck. Hence, the iron on the *Galilee* was practically all below the instruments, so that positive values of c and f indicate components of induced magnetism respectively forward of and to starboard of the instrument, and negative values indicate components abaft and to port. With these assumptions, the values of a', a'', and ρ' in Table 35 have been calculated. The varying values for different cruises, or even for parts of the same cruise, are explained by changes in the magnetism of the ship and by observational error. It is evident that if the parameters P, Q, c, and f are but little larger than the possible errors of their determinations, then the ratios $\frac{Q}{P}$ and $\frac{f}{c}$ must be very uncertain. Actual changes were made in the *Galilee* between cruises for the purpose of reducing the deviations. Other changes in the magnetism of the ship may occur from the continued buffeting of the sea while headed continuously in one direction.

[1]From August 24 to December 13, 1905.

DEVIATION-CONSTANTS FOR CHIEF VESSELS ENGAGED IN OCEAN MAGNETIC WORK.

Table 36 gives for the chief vessels which have been engaged in ocean magnetic work the 12 fundamental deviation-constants (or combinations of them) that represent the induced and permanent magnetic forces aboard ship. The data for the first four vessels have been taken from Bidlingmaier's article, page 486 of the 1905 edition of Neumayer's "Anleitungen[1]"; sm. in the table means a small value. The data for the *Discovery*, 1904, are taken from pages 148–149 of the volume on "Physical Observations of the National Antarctic Expedition, 1901–1904." A'_d and E'_d were assumed to be zero.[2]

It will be noticed that for the *Galilee*, at each instrument-position, the constants are, in general, smaller than those for previous vessels. Furthermore, the deviation-corrections for two different instrument-positions, *e.g.*, as used in getting H, are of varying amount and even of different sign, so that the resultant mean effects, as shown in the last column, are very small. The values in Table 36 are the means of the 3 cruises, giving each cruise equal weight.

TABLE 36.—*Deviation-Constants for the Chief Vessels which have been engaged in Ocean Magnetic Work.*

[All quantities are expressed in units of the third decimal except λ. P, Q, R are expressed in units of the third decimal C. G. S.]

Constant	Erebus, 1839 to 1842	Challenger, 1873 to 1876	Gazelle, 1874 to 1876	Gauss, 1901 to 1903	Discovery, 1904	Galilee, 1905–1908			
						Stand. Comp.	Sea Deflector	Sea Dip Circle	Mean
$\lambda = 1 + \left(\frac{a+e}{2}\right)$	0.991	0.999	0.980	1.003	0.973	....	1.000	.999	1.000
$A'_d = \frac{1}{\lambda}\left(\frac{d-b}{2}\right)$	0	+ 2	+ 6	+ 5	0	0	+1	....	0
$D'_d = \frac{1}{\lambda}\left(\frac{a-e}{2}\right)$	+ 7	+ 6	+11	+21	+ 19	+2	−2	+ 1	0
$E'_d = \frac{1}{\lambda}\left(\frac{d+b}{2}\right)$	sm.	0	− 2	0	0	−1	+1	0	0
g	+27	0	+13	− 5	....	....	....	− 1	− 1
h	sm.	0	+ 9	0	....	....	....	− 6	− 6
c	+26	+ 8	+21	−12	+ 3	0	+4	− 3	0
f	sm.	0	− 7	+ 1	0	0	0	+ 2	+ 1
k	+ 3	−33	−21	−13	− 22	....	....	− 8	− 8
P	sm.	+13	+ 8	+ 2	+ 3	0	0	0	0
Q	sm.	0	− 3	0	0	0	0	− 3	− 1
R	sm.	−40	− 2	− 2	+ 4	....	....	− 1	− 1

SPECIMEN COMPUTATIONS OF DEVIATION-CORRECTIONS.

As specimens, the deviation-corrections will be computed for April 14, 1908, the day on which the specimen observations, given on pages 46–53, were made. This day falls in group 6 of Cruise III (Callao to San Francisco).

Declination.—For the morning observations we have the approximate values $H = 0.328$ C. G. S., and $I = -0°.2$; for the afternoon observations, $H = 0.330$, and $I = +0°.1$. The course for both a. m. and p. m. was WSW; hence, $\zeta = 247°.5$. The deviation-correction, applied to both a. m. and p. m. declinations (see Table 37, p. 92), is $-0°.08$.

Inclination.—$H = 0.330$ C. G. S. approximately; $I = -0°.3$ approximately; course, W; hence, $\zeta = 270°$.

---

[1]See reference in footnote, p. 78.

[2]The following two departures from the generally accepted notation occur in the *Discovery* publication, viz, d has the meaning usually assigned to k, and V that usually assigned to R.

TABLE 37.—*Computation of Declination-Deviations for Standard-Compass (RSC) Position on April 14, 1908.*

Formula: $\delta D = A_d + B_d \sin \zeta + C_d \cos \zeta + D_d \sin 2\zeta + E_d \cos 2\zeta$

From Table 30 (p. 87): $A_d = -0\overset{\circ}{.}03$; $D_d = +0\overset{\circ}{.}10$; $E_d = 0\overset{\circ}{.}00$; $x = -0\overset{\circ}{.}1123$; $y = +0\overset{\circ}{.}0132$; $x' = +0\overset{\circ}{.}0563$; $y' = -0\overset{\circ}{.}0713$.

tan I	$\frac{1}{H}$	x tan I	$\frac{y}{H}$	B_d	x' tan I	$\frac{y'}{H}$	C_d	A_d	B_d sin ζ	C_d cos ζ	D_d sin 2ζ	E_d cos 2ζ	Deviation
		°	°	°	°	°	°	°	°	°	°	°	°
0.00	3.05	.000	+.040	+.04	.000	−.217	−.22	−.03	−.04	+.06	+.07	.00	+.06
0.00	3.03	.000	+.040	+.04	.000	−.216	−.22	−.03	−.04	+.06	+.07	.00	+.06

TABLE 38.—*Computation of Inclination-Deviations for Sea-Dip-Circle Position on April 14, 1908.*

Formula: $\delta I = A_i + B_i \cos \zeta + C_i \sin \zeta + D_i \cos 2\zeta + E_i \sin 2\zeta$

From Table 31 (p. 87): $x = +0\overset{\circ}{.}166$; $y = +0\overset{\circ}{.}149$; $s = +0\overset{\circ}{.}066$; $x' = +0\overset{\circ}{.}390$; $y' = +0\overset{\circ}{.}020$; $s' = +0\overset{\circ}{.}014$; $x'' = -0\overset{\circ}{.}100$; $-x''' = -0\overset{\circ}{.}014$.

For computing A_i from (32), $(\lambda - k - 1)/2 \sin 1° = +0\overset{\circ}{.}196$, and $R/\sin 1° = -0\overset{\circ}{.}055$ for all 3 cruises.

The computation assumes an approximate value of I of $-0\overset{\circ}{.}3$, which, when the deviation-correction, $+0\overset{\circ}{.}2$, is applied, becomes $-0\overset{\circ}{.}1$. A recomputation with this new value of I would not, however, make any material difference in the value of the deviation.

Horizontal Intensity.—The tabular arrangement adopted for the computation of the horizontal-intensity deviations is exemplified by the calculation of the value for April 14, 1908, at the sea-deflector position. $H = 3280$ approximately, in units of fourth decimal C. G. S.; $I = -0\overset{\circ}{.}3$ approximately; course, W, hence, $\zeta = 270°$. The resulting deviation-correction is +22 units in the fourth decimal C. G. S.

TABLE 39.—*Computation of the Horizontal-Intensity Deviations for Sea-Deflector Position on April 14, 1908.*

Formula: $\delta H = A_h + B_h \cos \zeta + C_h \sin \zeta + D_h \cos 2\zeta + E_h \sin 2\zeta$

From bottom line of Table 32 (p. 88): $P \cdot 10^4 = -4$; $Q \cdot 10^4 = -4$; $c = +.00043$; $f = -.00017$; $x' = +.00450$; $x'' = +.00102$.

Values of H, A_h, B_h, C_h, D_h, E_h, and the deviation are in units of the 4th decimal C. G. S.													
tan I	H tan I	cH tan I	B_h	fH tan I	C_h	D_h	E_h	A_h	B_h cos ζ	C_h sin ζ	D_h cos 2ζ	E_h sin 2ζ	Deviation
−.005	−16	0	−4	0	+4	+15	−3	−3	0	−4	−15	0	−22

The horizontal-intensity deviations for the *dip-circle position* were obtained on a form similar to that shown in Table 39.

OCEAN MAGNETIC OBSERVATIONS ON THE GALILEE, 1905-1908.

EXPLANATORY REMARKS.

As nearly as possible the same conventions have been followed in the presentation of the ocean magnetic results obtained on the *Galilee* during the three years August 1905 to May 1908 as adopted for the land magnetic results in Volumes I and II.

Stations.—It will be seen that the results are tabulated separately for each of the three cruises of the *Galilee*, all of which were in the Pacific Ocean. Next under each cruise the stations or points at which the observations were made are arranged chronologically, and they are numbered accordingly. Thus for Cruise I, the stations are numbered from 1 G I (Station 1 *Galilee* Cruise I) to 104 G I (Station 104 *Galilee* Cruise I) inclusive. Similarly for Cruise II, the numbering proceeds chronologically from 1 G II (Station 1 *Galilee* Cruise II) to 125 G II (Station 125 *Galilee* Cruise II). The stations for Cruise III proceed chronologically from 1 G III to 213 G III.

Geographic Positions.—The second and third columns contain, respectively, the latitude and longitude (counted east from Greenwich), expressed in degrees and minutes, to the nearest minute of arc. The latitudes and longitudes for the points of observation at sea were determined in accordance with the methods described on pages 58-60; in general they may be regarded as correct within 2 or 3 nautical miles. When no astronomical observations were possible for several days, the error in latitude, or in longitude, may amount to 5 or even 10 miles, depending upon circumstances. The geographic positions of the harbor stations are in general known within 1 minute of latitude and longitude.

Date.—The date on which the magnetic observations were made is recorded in the fourth column. The following abbreviations have been adopted for the months of the year: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec. The year is indicated at the head of the column.

Magnetic Elements.—The values of the magnetic elements (declination, inclination, and horizontal intensity) will be found in the next columns, preceded in each case by the local mean time (L. M. T.) of observation, expressed to nearest 0.1 of an hour. In cases where the observations which make up the mean value are numerous and are scattered over various parts of the day, so that the mean may be practically taken as the mean of day, the local mean times are replaced by the word "various"; in such cases the number of determinations from which the mean value is derived is indicated for the shore results (pp. 105-110), in general, by a number inclosed in parentheses. Where numerous observations were made during a certain interval, as during a vessel swing, it has appeared desirable to give the local mean times of the beginning and of the ending of the swing. The local mean times are given according to civil reckoning and are counted from midnight as zero hour continuously through 24 hours; 16^h, for example, means 4 o'clock p. m.

The ocean values of magnetic declination and inclination are given in degrees and minutes, to the nearest minute of arc. No claim, however, is made that they are correct to a minute of arc. In general the error in the tabulated value is about 5′ to 10′, or less; in some cases the error may be 15′ to 20′, depending on the severity of the conditions encountered during the observations. It was thought best to retain the original quantities resulting from the computations until the various corrections, mentioned below, had been applied. The error of a harbor result, usually depending upon extensive observations during the swing of the vessel, is generally not over 5′, and may be less. Only the mean

quantities resulting from the observations with all instruments used for any particular element are given. The letters *E* and *W* serve to indicate whether the magnetic declination is east or west of north. The letters *N* and *S* show whether the north-seeking end of the magnetic needle points below the horizon, as it does in the northern magnetic hemisphere, or above, as it does in the southern magnetic hemisphere.

The ocean values of horizontal intensity, derived as explained on pages 23–26 with all instruments employed, are tabulated to the fourth decimal of the C. G. S. unit of magnetic field-intensity. In magnetic-survey work on land the fourth decimal is often uncertain by one or more units, and in ocean work the error may approach a unit in the third decimal place. It is thus to be understood that no claim is made for the correctness of the last figure; it has been retained here primarily in order that when all reductions to common epoch have been applied on account of the various magnetic variations, the error (due purely to computation) will be kept down to the desired limit.

The question whether to give values of the horizontal intensity exclusively, or values of total intensity, was decided in the previous volumes, for reasons there stated, in favor of the former.

The instruments used are shown in the columns "Compass" and "Dip Circle." The designations of the various instruments employed will be found stated on pages 28–32. The term "Compass" also includes the "Sea Deflector," with which both declinations and horizontal intensities were observed, as described on pages 17–19. The term "Dip Circle" likewise includes the "Sea Dip-Circle" when used for determination of the total intensity from which the horizontal intensity is derived, as explained on page 23. The designation 169.12*34*, for example, means that dip circle 169 was used, the inclination being observed with regular dip needles 1 and 2, and with deflected needle 3, and that the total intensity was observed with the same instrument by the deflection method, using the intensity needles 3 and 4 (the ones italicized). Similarly 189.9,10,*78* means that inclination was observed with dip circle 189, using regular dip needles 9 and 10, and deflected needle 7, and that, furthermore, total intensity was obtained by the deflection method, using intensity needles 7 and 8. Invariably the intensity needles are italicized and are given last. The higher number of the two intensity needles always designates the chief intensity needle (the deflecting and the loaded needle). Whenever the total intensity was determined from both loaded-dip observations and deflections, this fact is shown by the addition of the dagger (†); thus, *e. g.*, 169.12*34*†, or 189.9,10,*78*†, as the case may be. When, as had to be the case with sea dip-circle 169 on a portion of the *Galilee's* first cruise (see p. 19), total intensity was obtained only with the loaded needle (No. 4), and the inclination was observed with the regular dip needles (Nos. 1 and 2), then the designation is 169.12*4*. By turning to the method of observations, pages 17–26, and 33–58, any additional explanation may be obtained. (See also inventory of instruments used aboard the *Galilee*, pp. 28-32).

The columns of "Remarks" contain:

a. Course. This is the ship's magnetic course (heading) on which the observations were made. When the word "swing" occurs this means that the vessel was swung during observations. A harbor-swing of vessel implies that the vessel was swung on at least 8 equidistant headings with both port and starboard helms. The swings at sea with a sailing vessel could rarely be complete, the aim, however, being, in general, to secure 8 equidistant headings; not infrequently one, two, or even three out of the desired 8 equidistant headings would be missed. For all swings, the local mean times given in the respective columns denote the times of beginning and ending of the swing. The deviation-coefficients and details regarding swings will be found in Tables 23 to 28, pages 81–85.

In the case of the *Carnegie*, because of the absence of deviation-corrections, it was also possible to make observations when the vessel's heading was shifting, as would be the case when the vessel was "becalmed," or "at anchor."

b. Roll. This column records the average *full* angle through which the ship rolled, from side to side; it is double the recorded clinometer-readings.

c. Sea. The state of the sea is indicated by the following symbols:

B.—Broken or irregular sea.	*H.*—Heavy sea.	*R.*—Rough sea.
C.—Chopping, short or cross sea.	*L.*—Long, rolling sea.	*S.*—Smooth sea.
G.—Ground swell.	*M.*—Moderate sea, or swell.	*T.*—Tide rips.

When different observers record the state of the sea independently, it frequently happens that their estimates or designations vary. In many of these cases one particular letter was selected, after a careful consideration of all the symbols given by the various observers, supplemented by the recorded ship's roll, and by other notes.

d. Weather. The symbols denoting the state of weather at the time are those in general use:

b.—Clear, blue sky.	*l.*—Lightning.	*s.*—Snow.
c.—Clouds.	*m.*—Misty.	*t.*—Thunder.
d.—Drizzling or light rain.	*o.*—Overcast	*u.*—Ugly appearances, threatening weather.
f.—Fog or foggy weather.	*p.*—Passing showers.	*v.*—Variable weather.
g.—Gloomy, dark, stormy.	*q.*—Squally.	*w.*—Wet or heavy dew.
h.—Hail.	*r.*—Rain.	*z.*—Hazy weather.

Weights.—The figures given in the column marked "Wt." are the weights assigned the results on the following scale, which expresses, in a general way, the conditions as to sea, weather, instruments and experience under which the observations were made: 1 denotes severe or adverse conditions; 2, medium conditions; and 3, favorable conditions.

The application of variation corrections to the observed results on account of the numerous variations of the Earth's magnetism, *e. g.*, diurnal variation, secular variation, magnetic perturbations, etc., is deferred to the volume in which all the magnetic data, obtained both on land and sea, will be summarized and reduced to a common epoch. (That volume, No. V, can not appear until some time after the completion of the present cruise of the *Carnegie* in 1917. Whether it will be worth while, in the case of the ocean data, to apply any other corrections than those on account of secular change will there receive consideration.)[1] To avoid undue delay in the promulgation of the accumulated data, and in view of the inaccuracies of the magnetic charts at present in use, it is considered best to publish the observed results as obtained with no corrections applied, except the reductions to the magnetic standards of the Department, as fully explained in the section on this subject. However, since for the magnetic elements tabulated the precise data and local mean time of each observation are given, the reader is supplied with the required information in case, for some purpose of his own, he desires to reduce the observed values to some mean time.

Local Magnetic Disturbance.—As in Volumes I and II, the asterisk (*) is used throughout to indicate a station where local magnetic disturbance is known to exist.

COMBINING WEIGHTS ASSIGNED TO DIFFERENT INSTRUMENTS AND METHODS.

The tabulated values of the magnetic elements are usually the weighted means of two or more results, obtained by means of two different instruments, or by two different methods.

To obtain the weighted value of the declination, the results of

Compass R1A (prism)	was given a weight 1	Cruise I
R1A (alidade)	was given a weight 1	
R1B (prism)	was given a weight 1	Cruise II
R1B (alidade)	was given a weight 1	
R3C (prism)	was given a weight 2	Cruise III
R3C (alidade)	was given a weight 2	
D2 (prism)	was given a weight 1	
D2 (alidade)	was given a weight 1	

[1]Volume IV is to contain the magnetic-survey results 1914–1917 and reports on special researches.

Double weight was given to the results with R3C for Cruise III for the reason that the declination deviation-coefficients were much better determined for the R3C position on the observing bridge than for the D2 position.

The weighted mean value of the inclination was obtained by assigning the weight 2 to the result of each dip needle and the weight 1 to the result of each complete observation of deflected dip. Hence, the deflected dip-results from long and short distance each received a weight of 1, or if the observation at one distance was repeated the result received a weight of 2. The weighted mean value of the horizontal intensity was obtained by assigning weights 3, 2, and 1 to the deflector results, the sea-dip-circle results by deflections, and the sea-dip-circle results by loaded needle, respectively, when they were obtained under normal sea conditions. But when the observations were made under unfavorable conditions of motion, or with small values of the horizontal intensity, the weights assigned were then 6, 4, 1 in the same order. In some exceptional cases equal weights were assigned the results obtained by deflector and by sea dip-circle, deflected dip, or loaded dip, as in the case of swings, exceptionally quiet conditions, etc.

DISTRIBUTION OF STATIONS.

Table 40 shows for each cruise of the *Galilee* the number of days consumed (adding to the days at sea those spent in the harbor-swings of vessel), the length of the cruise in nautical miles, the number of tabulated values, respectively, of declination, inclination, and horizontal intensity, next the average time-interval between observations, as well as the average distance apart. It will be seen that, for the total length of the *Galilee's* three cruises (63,834 nautical miles in the Pacific Ocean), the magnetic observations, whether of declination, inclination, or horizontal intensity, were made, on the average, every two days apart in time and about 200 miles in distance.

TABLE 40.—*Summary showing the Distribution of the Galilee Magnetic Observations 1905-1908.*

Cruise	Number		Number of Stations			Average Time-Interval			Average Distance Apart		
	Days	Miles	Decl'n	Incl'n	Hor. Int.	Decl'n	Incl'n	Hor. Int.	Decl'n	Incl'n	Hor. Int.
						d	*d*	*d*	*miles*	*miles*	*miles*
I, 1905.........	92	10,571	74	58	59	1.2	1.6	1.6	143	182	179
II, 1906.........	168	16,286	95	88	91	1.8	1.9	1.8	171	185	179
III, 1906–1908....	334	36,977	156	169	171	2.1	2.0	2.0	237	219	216
I, II, and III.....	594	63,834	325	315	321	1.8	1.9	1.9	196	203	199

OBSERVERS AND COMPUTERS.

The Table of Ocean Results differs from the Table of Land Results, published in Volumes I and II, in one other respect besides those already shown in the foregoing explanations, viz, that the observers' initials, for practical reasons, had to be omitted. The magnetic results for any one day are the combined product of all the observers aboard at the time. Those who took part in the observations for the various cruises of the *Galilee* are as follows:

Cruise I.—J. P. Ault, L. A. Bauer, J. H. Egbert, J. F. Pratt, and P. C. Whitney.
Cruise II.—J. P. Ault, H. E. Martyn, J. C. Pearson, and W. J. Peters.
Cruise III.—P. H. Dike (beginning August 1907), J. C. Pearson (to July 1907), W. J. Peters, G. Peterson, and D. C. Sowers.

The chief persons who have taken part, at various times, in the comparisons and determination of instrumental constants at Washington, in the final office reductions, or in the preparation of results for publication, are: *J. P. Ault*, *L. A. Bauer*, J. J. Carey, P. H. Dike, *C. R. Duvall*, H. M. W. Edmonds, *C. C. Ennis*, *H. W. Fisk*, *J. A. Fleming*, H. D. Harradon, H. F. Johnston, R. R. Mills, J. H. Millsaps, J. C. Pearson, *W. J. Peters*, A. D. Power, H. R. Schmitt, D. C. Sowers, and J. A. Widmer. Those whose names are italicized have borne the brunt of the work at Washington.

FINAL RESULTS OF OCEAN MAGNETIC OBSERVATIONS ON THE GALILEE, 1905–1908.

CRUISE I, PACIFIC OCEAN, 1905.

*Local Disturbance

CRUISE I, PACIFIC OCEAN, 1905—*Concluded.*

*Local Disturbance.

CRUISE II, PACIFIC OCEAN, 1906.

CRUISE II, PACIFIC OCEAN, 1906—*Concluded.*

[1]Crossed 180th meridian; hence date, Sept. 27, repeated.

CRUISE III, PACIFIC OCEAN, 1906–1908.

[9] Local disturbance.

[4] From March 2–14 the Galilee was at Apia.

CRUISE III, PACIFIC OCEAN, 1906–1908—*Continued.*

Station	Latitude	Long. East of Gr.	Date	Declination L. M. T.	Declination Value	Declination Wt.	Inclination L. M. T.	Inclination Value	Inclination Wt.	Hor. Intensity L. M. T.	Hor. Intensity Value	Hor. Intensity Wt.	Instruments Compass	Instruments Dip Circle	Remarks Course	Remarks Roll	Remarks Sea
	° ′	° ′	*1907*	h h	° ′		h h	° ′		h h	c.g.s.					°	
56GIII	22 43 N	134 21	Apr 30	....	....	..	16.7	31 20 N	1	16.7	.3425	1	D1	35.1234†	NNW	24	MR
57GIII	23 39 N	134 00	May 1	6.5	1 49 W	2	....	....	..	....	....	..	R3C	....	N	16	S
58GIII	24 46 N	133 26	May 1	15.7 to 17.9	1 56 W	3	15.4 to 18.0	34 10 N	3	15.4 to 18.0	.3429	3	R3C, D1	35.134	Swing	15	MR
59GIII	27 56 N	130 20	May 3	16.9	2 48 W	2	....	....	..	....	....	..	R3C	....	N	30	MR
			May 3	....	....	..	16.9	40 13 N	2	16.9	.3360	2	D1	169.1278†	NNW	30	MR
60GIII*	31 02 N (Yangtse R.)	122 10	May 31 Jun 1	[1]14.9 to [1]17.0	2 48 W	3	Various	44 50 N	3	Various	.3354	3	R3C, D1	35.234	Swings	0	S
61GIII	29 56 N	126 24	Jun 7	16.6	3 08 W	2	....	....	..	....	....	..	R3C	....	ENE	14	S
			Jun 7	....	....	..	16.6	43 46 N	2	16.6	.3323	2	D1	35.1234†	E	14	S
62GIII	29 56 N	126 27	Jun 7	18.4	3 07 W	2	....	....	..	....	....	..	R3C	....	E	6	S
63GIII	29 35 N	127 22	Jun 8	....	....	..	16.3 to 18.0	42 31 N	2	16.5 to 17.8	.3337	2	D1	169.1278†	N, NNE	4	S
			Jun 8	17.0	3 13 W	2	....	....	..	....	....	..	R3C	....	NNE	4	S
64GIII	30 12 N	133 23	Jun 12	16.4 to 18.4	3 47 W	3	17.2 to 18.5	42 49 N	3	15.8 to 18.6	.3212	3	R3C, D1	169.78†	Swing	12	M
65GIII	30 48 N	146 20	Jun 16	17.7	2 14 W	2	17.5	42 32 N	2	17.6	.3058	2	R3C, D1	35.1234†	E	40	M
66GIII	35 12 N	159 36	Jun 22	17.6	1 00 E	2	17.5	46 44 N	1	17.5	.2820	2	R3C, D1	169.1278†	E	40	L
67GIII	35 11 N	161 47	Jun 23	....	....	..	17.1	47 22 N	2	17.1	.2796	2	D1	35.1234†	E	13	M
68GIII	35 10 N	161 47	Jun 23	18.3	2 14 E	2	....	....	..	....	....	..	R3C	....	E	10	S
69GIII	36 55 N	164 07	Jun 25	....	....	..	17.2 to 18.4	49 33 N	3	15.9 to 18.4	.2717	3	D1	35.34†	Swing	20	S
70GIII	36 55 N	164 07	Jun 25	17.4	2 41 E	1	....	....	..	....	....	..	R3C	....	S	30	S
71GIII	37 07 N	181 37	Jul 2	....	....	..	13.7	52 20 N	1	14.5	.2559	2	D1	169.1	NE	40	LR
72GIII	39 34 N	185 40	Jul 3	17.4	11 52 E	2	17.4	54 47 N	2	17.4	.2519	2	R3C, D1	169.1278†	NE	10	M
73GIII	39 39 N	185 49	Jul 3	18.3	11 55 E	2	....	....	..	....	....	..	R3C	....	NE	16	M
74GIII	41 48 N	190 10	Jul 4	17.6	13 24 E	2	17.4	57 28 N	2	17.4	.2445	2	R3C, D1	35.1234†	NE	6	M
75GIII	44 01 N	194 40	Jul 5	....	....	..	17.0	59 42 N	2	17.0	.2387	2	D1	169.1278†	NE	40	MR
76GIII	45 42 N	198 56	Jul 8	....	....	..	16.4	61 48 N	1	16.4	.2312	2	D1	35.1234†	NE	14	MR
77GIII	47 46 N	203 37	Jul 9	....	....	..	16.8	63 59 N	1	16.7	.2224	2	D1	169.1278†	NE	40	M
78GIII	49 30 N	207 28	Jul 10	....	....	..	16.9	66 01 N	2	16.9	.2137	2	D1	35.1234†	NE	10	M
79GIII	54 05 N	217 47	Jul 12	19.0	24 07 E	1	....	....	..	....	....	..	R3C	....	NNE	16	R
80GIII	57 03 N (Off Sitka)	224 40	Jul 16 Jul 17	Various	30 05 E	3	Various	74 29 N	3	Various	.1571	3	R3C, D1	169.78†	Swings	0	S
			Jul 17 Jul 18 Jul 19	Various	30 01 E	3	Various	74 36 N	3	Various	.1564	3	R3C, D1	35.234	Swings	0	S
81GIII	55 42 N	221 07	Aug 12	7.6	27 55 E	2	....	....	..	....	....	..	R3C, D2	....	S	0	S
82GIII	54 37 N	221 00	Aug 12	....	....	..	15.8	72 31 N	2	15.8	.1715	2	D2	189.5634†	S	12	S
83GIII	53 48 N	220 13	Aug 13	....	....	..	....	....	..	15.6 to 17.0	.1814	3	D2	....	Swing	18	S
84GIII	53 48 N	220 13	Aug 13	15.9	26 03 E	1	....	....	..	....	....	..	R3C	....	S, SE	....	M
85GIII	45 25 N	222 51	Aug 16	....	....	..	16.0 to 17.2	65 50 N	3	16.0 to 18.2	.2212	3	D2	189.34†	Swing	26	M
			Aug 16	16.3	22 44 E	1	....	....	..	....	....	..	R3C	....	W	....	M
86GIII	43 07 N	222 47	Aug 17	17.3	20 27 E	1	17.2	63 24 N	2	17.3	.2331	2	R3C, D2	169.1278†	S	28	M
87GIII	43 03 N	222 45	Aug 17	18.4	20 13 E	2	....	....	..	....	....	..	R3C, D2	....	S, SSE	0	S
88GIII	41 09 N	222 38	Aug 18	....	....	..	17.4	62 21 N	2	17.4	.2404	2	D2	189.5634†	SW	16	S
89GIII	39 26 N	222 30	Aug 19	16.2 to 17.3	18 27 E	3	15.8 to 18.4	60 45 N	3	15.9 to 18.4	.2507	3	R3C, D2	169.178	Swing	32	S
90GIII	36 56 N	221 59	Aug 20	17.3	17 32 E	1	17.3	58 36 N	2	17.4	.2569	2	R3C, D2	189.5634†	SSW	30	M
91GIII	34 50 N	219 29	Aug 21	17.4	16 19 E	1	17.3	56 06 N	2	17.4	.2651	2	R3C, D2	169.1278†	SSW	40	M
92GIII	33 02 N	216 59	Aug 22	16.9	15 37 E	2	17.0	54 05 N	2	17.0	.2692	2	R3C, D2	189.5634†	SW	20	M
93GIII	31 45 N	215 18	Aug 23	17.1	14 40 E	2	17.0	52 50 N	2	17.0	.2730	2	R3C, D2	169.1278†	SW	0	S
94GIII	31 02 N	214 18	Aug 24	....	....	..	8.6 to 10.6	51 13 N	3	8.6 to 10.7	.2755	3	D2	189.534	Swing	18	S
95GIII	30 34 N	213 46	Aug 24	17.4	13 49 E	3	....	....	..	....	....	..	R3C, D2	....	SW	....	S
96GIII	28 20 N	211 06	Aug 25	17.1	12 56 E	2	17.2	48 46 N	2	17.2	.2798	2	R3C, D2	189.5634†	SW	6	M
97GIII	25 45 N	208 17	Aug 26	....	....	..	16.2	45 07 N	1	16.4	.2840	1	D2	169.12	S	46	R
98GIII	22 44 N	204 57	Aug 27	17.6	10 43 E	2	17.4	41 37 N	1	17.6	.2913	1	R3C, D2	169.1278†	SW	34	M
99GIII*	21 16 N (Near Honolulu)	202 03	Aug 29	7.6 to 10.5	10 37 E	3	7.7 to 10.5	39 12 N	3	7.7 to 10.5	.2916	3	R3C, D2	189.534	Swing	0	S
100GIII	21 50 N	199 12	Sep 27	15.9 to 17.0	10 28 E	1	....	....	..	....	....	..	R3C	....	N, NW	30	M
			Sep 27	....	....	..	15.8 to 17.0	39 37 N	3	15.8 to 17.7	.2909	3	D2	189.34	Swing	40	M
101GIII	22 55 N	196 21	Sep 28	17.0	10 34 E	2	16.9	40 58 N	2	17.0	.2872	2	R3C, D2	169.1278†	W	10	SR
102GIII	23 34 N	193 16	Sep 29	16.9	10 58 E	2	16.7	40 53 N	2	16.7	.2858	2	R3C, D2	189.5634†	W	20	SR
103GIII	27 40 N	183 47	Oct 4	....	....	..	7.1	43 02 N	2	7.1	.2799	2	D2	169.1278†	NW	6	M
104GIII	26 07 N	181 10	Oct 6	....	....	..	17.0	40 53 N	2	16.9	.2821	2	D2	189.5634†	S	22	M
105GIII	26 03 N	181 09	Oct 6	17.3	9 56 E	2	....	....	..	....	....	..	R3C, D2	....	S	36	M
106GIII	23 22 N	179 27	Oct 7	15.5 to 17.4	9 45 E	3	15.4 to 16.4	37 02 N	3	15.4 to 17.4	.2896	3	R3C, D2	169.78†	Swing	15	S
107GIII	20 38 N	177 48	Oct 9	17.0	9 10 E	3	17.0	33 03 N	1	17.0	.2983	2	R3C, D2	169.1278†	S	50	M
108GIII	12 32 N	172 36	Oct 12	....	....	..	5.9 to 8.0	19 03 N	3	5.9 to 7.8	.3225	3	D2	189.534	Swing	20	M
			Oct 12	7.2	8 55 E	1	....	....	..	....	....	..	R3C	....	NW	20	M
109GIII	11 34 N	172 05	Oct 12	17.6	8 44 E	2	....	....	..	....	....	..	R3C, D2	....	S	20	S
110GIII	9 28 N	171 13	Oct 13	16.6	8 40 E	3	16.7	13 07 N	2	16.6	.3343	2	R3C, D2	189.5634†	SW	10	S

*Local disturbance.

[1]May 31, 1907.

CRUISE III, PACIFIC OCEAN, 1906–1908—*Continued.*

CRUISE III, PACIFIC OCEAN, 1906–1908—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination			Inclination			Hor. Intensity			Instruments		Remarks	
				L. M. T.	Value	Wt.	L. M. T.	Value	Wt.	L. M. T.	Value	Wt.	Compass	Dip Circle	Course	Roll
	° ′	° ′	*1908*	h h	° ′		h h	° ′		h h	c.g.s.					°
172GIII	17 56 S	275 51	Mar 5	17.2	11 53 E	2	17.1	17 55 S	2	17.0	.2920	2	R3C, D2	189.5634†	NE	8
173GIII	17 27 S	276 58	Mar 6	6.0 to 6.9	11 50 E	3							R3C		Swing	6
174GIII	17 27 S	276 59	Mar 6				8.0 to 8.6	15 44 S	3	8.0 to 9.8	.2947	3	D2	189.34†	Swing	6
175GIII	15 04 S	280 32	Mar 8	17.2	11 26 E	2	17.2	9 36 S	2	17.2	.2947	2	R3C, D2	169.1278†	NE	13
176GIII	13 12 S	282 34	Mar 9	17.2	9 32 E	2	17.1	5 20 S	2	17.1	.2948	2	R3C, D2	189.5634†	NNE	8
177GIII	12 04 S (Off Callao)	282 47	Apr 4	15.2 to 17.8	9 13 E	3	16.5 to 17.8	3 23 S	3	15.2 to 17.8	.2986	3	R3C, D2	169.78†	Swing	0
178GIII	11 32 S	281 47	Apr 6				17.0	3 10 S	2	17.0	.2992	2	D2	169.1278†	W	25
			Apr 6	17.1	9 25 E	2							R3C, D2		WNW	25
179GIII	11 00 S	279 48	Apr 7	17.0	9 29 E	1	16.9	3 16 S	2	16.9	.3014	2	R3C, D2	189.5634†	WNW, W	13
180GIII	10 58 S	279 42	Apr 7	17.7	9 23 E	2							R3C, D2		WNW	13
181GIII	10 16 S	277 26	Apr 8				16.7	2 52 S	2	16.7	.3072	2	D2	169.1278†	W	35
182GIII	10 15 S	277 22	Apr 8	17.4	9 25 E	2							R3C, D2		NW	35
183GIII	9 33 S	274 53	Apr 9				15.3 to 17.3	2 29 S	3	15.5 to 17.3	.3117	3	D2	189.534	Swing	30
184GIII	8 48 S	272 02	Apr 10	17.0	9 40 E	2	17.1	1 55 S	2	17.0	.3160	2	R3C, D2	189.5634†	NW, W	30
185GIII	8 05 S	269 26	Apr 11				16.8	1 53 S	1	16.8	.3196	2	D2	169.1278†	W	30
186GIII	6 31 S	263 45	Apr 13				15.2 to 16.8	0 29 S	3	15.2 to 16.8	.3277	3	D2	169.178	Swing	33
187GIII	6 01 S	261 30	Apr 14	6.3	8 44 E	2							R3C, D2		WSW	30
188GIII	5 41 S	260 05	Apr 14	16.9	8 59 E	2							R3C, D2		WSW	20
			Apr 14				16.9	0 05 S	2	16.9	.3296	2	D2	189.5634†	W	30
189GIII	4 54 S	255 01	Apr 16	16.8	9 01 E	2							R3C, D2		NW	35
			Apr 16				16.9	0 01 S	2	16.8	.3313	2	D2	169.1278†	W	35
190GIII	4 25 S	252 48	Apr 17	15.6 to 17.3	8 52 E	3	15.5 to 16.2	0 10 N	3	15.5 to 17.2	.3359	3	R3C, D2	189.34†	Swing	30
191GIII	3 40 S	250 59	Apr 18	16.8	8 56 E	2							R3C, D2		WNW	30
			Apr 18				17.0	0 13 N	2	17.0	.3349	2	D2	189.5634†	W	30
192GIII	1 54 S	247 03	Apr 20				16.9	4 06 N	2	16.8	.3392	2	D2	169.1278†	WNW	30
193GIII	0 44 S	246 32	Apr 21	16.9	8 10 E	2	16.9	5 56 N	2	16.9	.3407	2	R3C, D2	189.5634†	NW	12
194GIII	0 34 N	246 47	Apr 22	16.9	8 16 E	2	16.9	8 50 N	2	16.9	.3415	2	R3C, D2	169.1278†	NW	30
195GIII	2 30 N	246 24	Apr 23	16.9	8 04 E	2	16.9	12 15 N	2	16.9	.3436	2	R3C, D2	189.5634†	N	13
196GIII	5 00 N	246 08	Apr 24				16.8	17 38 N	2	16.7	.3441	2	D2	169.1278†	N	26
197GIII	5 04 N	246 08	Apr 24	17.5	7 55 E	2							R3C, D2		N	30
198GIII	6 35 N	246 10	Apr 25				16.3	20 37 N	1	16.8	.3435	1	D2	189.5634†	N	25
199GIII	11 42 N	246 04	Apr 30	6.6	8 35 E	2							R3C, D2		NE	....
200GIII	12 43 N	245 43	May 1	6.0	9 06 E	2							R3C, D2		NW	....
201GIII	13 04 N	245 20	May 1				16.0	32 01 N	2	16.0	.3400	2	D2	169.1278†	WNW	10
202GIII	13 56 N	243 40	May 2				16.6	33 20 N	2	16.6	.3371	2	D2	189.5634†	WNW	8
203GIII	16 33 N	240 12	May 4				13.2 to 13.8	37 08 N	3	13.2 to 14.6	.3308	3	D2	169.78†	Swing	15
204GIII	16 44 N	239 52	May 4	18.0	10 02 E	2							R3C, D2		WNW	10
205GIII	17 56 N	237 59	May 5	16.8	10 11 E	2	16.9	38 58 N	2	16.8	.3255	2	R3C, D2	169.1278†	WNW	10
206GIII	18 51 N	235 53	May 6				16.4	40 18 N	2	16.3	.3216	2	D2	189.5634†	WNW	10
207GIII	28 08 N	226 00	May 11				16.6	50 05 N	2	16.6	.2889	2	D2	169.1278†	W	13
208GIII	29 34 N	224 20	May 12				16.7	51 37 N	2	16.7	.2832	2	D2	189.5634†	WNW	6
209GIII	30 21 N	223 38	May 13	18.0	14 31 E	2							R3C, D2		WNW	0
210GIII	31 28 N	222 49	May 16				15.9 to 17.2	53 20 N	3	15.6 to 17.2	.2779	3	D2	189.534	Swing	0
211GIII	31 35 N	222 53	May 16	18.3	14 29 E	2							R3C, D2		N	0
212GIII	37 47 N	232 49	May 20	16.8	17 20 E	2	16.8	61 16 N	2	16.8	.2546	2	R3C, D2	169.1278†	NE	10
213GIII	37 51 N	237 37	May 23	7.8 to 10.1	17 58 E	3	7.8 to 10.1	62 04 N	3	7.8 to 10.2	.2528	3	R3C, D2	169.178	Swing	0
	(San Francisco		May 25	5.4 to 7.6	17 58 E	3	5.4 to 6.6	62 05 N	3	5.4 to 7.7	.2518	3	R3C, D2	189.34†	Swing	0
	Bay)		May 28	5.0 to 8.4	17 57 E	3	7.5 to 9.7	62 07 N	3	5.0 to 9.7	.2524	3	R3C, D2	189.534	Swing	0

SHORE MAGNETIC OBSERVATIONS FOR THE GALILEE WORK, 1905-1908.

EXPLANATORY REMARKS.

The following results of shore magnetic observations, made in the course of the *Galilee* work of 1905 to 1908, are extracted from Volume I, pages 69, 72, 75, 87, 89, 90, 94, 98, 99, 100, using the same conventions as in that volume, to which reference should be made if fuller information is desired. (See also pages 93 and 94 of present volume.) These shore results were usually obtained in connection with the comparisons of ship and land instruments made at every port of call of the vessel. Sometimes additional observations were made, in view of the disclosure of local magnetic disturbances, or for the purpose of obtaining secular-variation data. The last column, headed "Obs'r" (Observer), shows the particular cruise of the *Galilee* on which the results were obtained. Thus GI, GII, and GIII, stand, respectively, for *Galilee* Cruise I, *Galilee* Cruise II, and *Galilee* Cruise III.

When the number of an instrument in the magnetometer column is italicized, it means that a dip circle was used to get the declination and horizontal intensity, the former by the means of the compass attachment and the latter by the total-intensity method.

RESULTS OF SHORE MAGNETIC OBSERVATIONS, 1905–1908.

ASIA.

China.

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Woosung, *13*	31 22 N	121 31	May 21,'07	11.0, 12.2	2 52.1 W	12.6	45 36.4 N	11.5	.33117	1	178.12	G III
Woosung, *12*	31 21.4 N	121 30	May 21, 07	15.0, 16.4, 17.0	2 49.8 W	17.7	45 32.0 N	15.5, 16.0	.33202	1	178.12	G III
			May 23, 07			9.5 (wt.½)	45 27.3 N				35.12	G III
Zikawei Obs'y, *Absolute House*	31 11.5 N	121 26	May 14, 07	14.0, 15.4	2 36.6 W			14.5, 15.0	.33087	1		G III
			May 15, 07			15.1	45 35.9 N				35.12	G III
			May 15, 07			17.0	45 41.9 N				169.12	G III
			May 17, 07			9.7, 11.0	45 35.0 N				35.12	G III
			May 17, 07			16.5	45 41.3 N				169.12	G III
			May 18, 07			9.2	45 36.9 N				178.12	G III
Zikawei Obs'y, *N.*	31 11.5 N	121 26	May 14, 07	10.1, 11.6	2 35.6 W	16.4	45 38.6 N	10.6, 11.1	.33048	1	178.12	G III
			May 15, 07	10.8, 12.0	2 38.4 W			11.2, 11.7	.33095	1		G III
			May 17, 07			10.2, 11.5	45 39.8 N				169.12	G III
			May 18, 07			11.2	45 36.8 N				178.12	G III

Japan.

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Tokio	35 42 N	139 46	Aug 15,'06	16.4, 17.9	4 42.8 W			16.9, 17.5	.30056	36		G II
			Aug 16, 06	9.7, 11.2	4 45.0 W	12.6	48 52.1 N	10.1, 10.9	.30044	36	178.1256	G II
			Sep 3, 06	14.1, 16.0	4 42.9 W			14.7, 15.6	.30068	36		G II
Tokio, *Secondary*	35 42 N	139 46	Aug 15, 06			16.8	48 50.2 N				35.25	G II
			Aug 16, 06			10.2, 11.8	48 52.4 N				35.25	G II
Kisarazu	35 23 N	139 55	Aug 19, 06	9.0, 10.3	4 41.4 W			9.4, 10.0	.30085	36		G II
Kisarazu, *Secondary*	35 23 N	139 55	Aug 19, 06			9.4	48 26.9 N				178.1256	G II
Sugita	35 22.7 N	139 38	Aug 20, 06	11.4, 12.6	4 55.3 W			11.7, 12.2	.30106	36		G II
Sugita, *Secondary*	35 22.7 N	139 38	Aug 20, 06			11.7	48 31.6 N				178.56	G II

AUSTRALASIA.

NEW ZEALAND.

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments	
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.		
Christchurch, *Absolute Magnetic Observatory*	43 31.8 S	172 37	Dec 31,'07	15.6, 17.4	16 35.8 E			16.6	.22618	4	
			Jan 3, 08	15.3, 17.1	16 36.9 E			16.1	.22624	4	
			Jan 6, 08	15.7	16 40.9 E	12.6	67 50.7 S	16.5	.22615	4	178.12
Christchurch Observatory, *Brass Pipe*	43 31.8 S	172 37	Dec 30, 07			16.0	67 50.7 S				178.12
			Dec 31, 07	11.3, 13.1	16 36.2 E			12.2	.22578	4	
			Jan 3, 08			12.4	67 51.9 S				189.56
			Jan 4, 08	11.3, 12.9	16 37.6 E			12.0, 15.1	.22615	4	
Christchurch Observatory, *near Brass Pipe*	43 31.8 S	172 37	Dec 31, 07			10.9, 11.8	67 52.6 S				169.12
			Dec 31, 07			15.4, 16.4	67 51.0 S				169.12
Christchurch Observatory, *Peg A*	43 31.8 S	172 37	Jan 3, 08			15.1, 16.5	67 50.2 S				189.56
			Jan 3, 08			17.7	67 52.0 S				178.12
New Brighton Beach	43 31.8 S	172 44	Jan 9, 08	11.5, 13.1	16 46.8 E	15.4	67 49.1 S	12.0, 12.7	.22692	4	178.12

NORTH AMERICA.

UNITED STATES.

Station	Latitude	Long. East of Gr.	Date	Declination L. M. T.	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value	Mag'r	Dip Circle
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.		
Sitka, *Absolute Obs'y*	57 03.0 N	224 40	Jul 22,'07	14.0, 15.3	29 58.2 E	16.2, 17.1	74 37.0 N	14.4, 15.0	.15546	1	178.12
			Jul 23, 07	9.3, 10.6	30 09.0 E	11.4	74 40.5 N	9.7, 10.2	.15524	1	178.12
			Jul 23, 07			15.2, 16.6	74 40.4 N				35.12
			Jul 24, 07			9.9, 11.1	74 40.9 N				35.12
			Jul 24, 07			15.4	74 40.6 N				169.12
			Jul 25, 07			14.4, 16.1	74 40.1 N				169.12
			Jul 29, 07	16.1	30 08.4 E			16.6, 17.3	.15530	4	
			Jul 30, 07	9.4, 11.1	30 11.8 E			9.9, 10.6	.15529	4	
			Jul 30, 07	15.6, 17.2	30 02.7 E			16.0, 16.7	.15516	4	
			Jul 31, 07			11.8	74 37.9 N				189.56
			Aug 1, 07			9.7, 10.9	74 37.5 N				189.56
			Aug 1, 07			14.6, 16.4	74 39.6 N				189.56
			Aug 2, 07			10.5	74 37.4 N				189.56
Sitka, *Auxiliary Obs'y*	57 03.0 N	224 40	Jul 24, 07	14.6	30 01.6 E			15.0, 15.7	.15566	1	
			Jul 25, 07	9.2, 10.6, 11.7	30 06.4 E	11.2	74 36.2 N	9.6, 10.3	.15562	1	178.12
			Jul 26, 07			16.6, 17.5	74 37.1 N				178.12
			Jul 29, 07	13.5, 15.4	30 04.2 E			14.0, 14.9	.15546	4	
			Jul 30, 07	13.4, 15.0	30 02.6 E			13.8, 14.6	.15547	4	
			Jul 31, 07	8.6, 10.3	30 13.7 E			9.0, 9.9	.15576	4	
			Jul 31, 07	13.4, 14.8	30 06.2 E			11.0, 11.6	.15552	4	
			Jul 31, 07					13.8, 14.4	.15564	4	
Kutkan Island	57 02 N	224 40	Jul 26, 07	14.6, 16.0	30 16.4 E			15.0, 15.7	.15676	1	
			Jul 23, 07			15.4	74 30.0 N				178.12
Baldwin, *Absolute Obs'y*	38 47.0 N	264 50	Dec 29, 06	9.8, 12.6	8 28.4 E	14.6 (wt.½)	68 40.0 N	11.1, 12.1	.21793	36	169.12
			Dec 29, 06			8.7, 16.1	68 44.8 N				171.12
			Dec 30, 06	7.8, 9.6	8 31.6 E	10.4 (wt.½)	68 43.6 N	8.3, 9.2	.21808	36	169.12
			Jan 11, 08			15.0	68 43.1 N				171.12
			Nov 13, 08	13.9	8 29.3 E			14.3	.21781	30	
			Nov 14, 08			11.7, 13.8	68 46.0 N				178.12
			Nov 14, 08			14.7 ...	68 44.2 N				178.56
			Nov 14, 08			10.9 ..	68 47.6 N				4655.34
			Nov 15, 08			9.5, 10.1	68 43.6 N				178.125
			Nov 15, 08			8.9	68 45.3 N				4655.34
			Nov 21, 08			10.3, 13.9	68 45.4 N				178.12
			Nov 21, 08			15.7 ...	68 47.2 N				178.56
			Nov 22, 08			9.0 ..	68 45.0 N				178.12
Baldwin, *Tent*	38 47.0 N	264 50	Nov 13, 08	14.0	8 26.5 E					36	
			Nov 14, 08			10.9, 13.3	68 43.2 N				178.12
			Nov 14, 08			16.0	68 43.7 N				178.56
			Nov 14, 08			11.8, 14.3	68 44.8 N				4655.34
			Nov 15, 08			8.2, 8.9	68 42.8 N				178.125
			Nov 15, 08			9.7	68 46.0 N				4655.34

NORTH AMERICA.

UNITED STATES—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
San Rafael, *C. & G. S. '97, Magnetometer Station*	37 58.6 N	237 27	Jul 27,'05	9.6, 11.4	17 38.6 E	12.6	62 13.9 N	10.1, 11.0	.25157	36	171.12	G I
			May 26, 08	13.0, 15.4	17 50.6 E			13.6, 14.8	.25100	4		G III
			May 27, 08	11.2, 12.0	17 52.0 E			10.7, 11.5	.25138	4		G III
San Rafael, *C. & G. S. '97, Dip Station*	37 58.6 N	237 27	Jul 27, 05			13.6, 14.0	62 13.0 N				171.12	G I
			May 27, 08			8.9, 16.0	62 14.8 N				178.12	G III
San Rafael, *North Pier*	37 58.6 N	237 27	May 27, 08	13.4, 15.1	17 51.3 E			13.8, 14.6	.25120	4		G III
			May 26, 08			16.5	62 16.8 N				178.12	G III
Berkeley	37 52.2 N	237 44	Jul 25, 05	11.0	17 32.3 E	11.7 13.1	62 10.2 N	12.5, 13.8	*.25816*	*169*	169.12	G I
Goat Island, San Fran. Bay	37 48.7 N	237 38	Jul 14, 05	10.2, 12.0	17 34.2 E			10.9, 11.8	.25256	36		G I
			Jul 14, 05	13.2, 15.0	17 34.0 E			13.8, 14.8	.25299	36		G I
			Jul 15–21			Various	62 06.0 N				Various	G I
			Jul 22, 05	11.3, 13.5	17 36.2 E			12.2, 13.2	.25276	36		G I
			May 29, 08	10.1, 11.7	17 50.6 E			10.5, 11.2	.25225	4		G III
			May 29, 08	12.8, 14.3	17 47.8 E	9.1 15.1	62 05.6 N	13.2, 13.9	.25252	4	178.12	G III
			May 30, 08	11.6, 15.0	17 52.1 E	16.2	62 05.0 N	12.4, 14.3	.25234	4	178.12	G III
			May 26–27			Various	62 05.3 N				Various	G III
Goat Island, *First Secondary*	37 48.7 N	237 38	May 30, 08			14.0	62 05.8 N				178.12	G III
			May 30, 08			12.6, 14.9	62 06.5 N				189.56	G III
San Francisco, Presidio[1]	37 47.5 N	237 32	Jul 17, 05	15.0	16 55.2 E	13.6	62 43.0 N	14.3 ...	*.24878*	*169*	169.12	G I
San Diego *III*	32 44.7 N	242 48	Aug 21, 05	15.8 16.0 ...	14 38.8 E					36		G I
			Dec 14, 05	10.9, 13.3	14 40.4 E	14.8	58 03.4 N	11.8, 12.8	.27693	36	171.12	G I
			Dec 15, 05			9.5 (wt. ½)	58 07.4 N				169.12	G I
San Diego, *C. & G. S. 1897*	32 42 N	242 46	Aug 14, 05	11.2, 13.8	13 58.7 E	14.5 (wt. ½)	58 09.2 N	11.6, 12.4	.27675	36	169.12	G I
			Aug 14, 05			16.0	58 04.7 N				171.12	G I
San Diego, *II*	32 40.9 N	242 48	Aug 19, 05	13.9, 15.4	14 27.6 E	11.5	58 02.5 N	14.3, 15.0	.27680	36	171.12	G I
San Diego, *I*	32 40.8 N	242 47	Aug 16, 05	14.4, 15.7	14 40.8 E	11.4	58 05.4 N	14.7, 15.3	.27730	36	171.12	G I
			Aug 17, 05			10.8 (wt. ½)	58 06.4 N				169.12	G I
			Aug 21, 05	10.2, 10.7	14 40.2 E					36		G I
			Dec 16, 05	13.7	14 41.9 E	12.1	58 05.0 N	14.1, 14.7	.27734	36	171.12	G I
			Dec 18, 05			12.1 (wt. ½)	58 08.0 N				169.12	G I
			Jan 20 to Feb 3, 06			Various	58 05.9 N				Various	G II
			Jan 23, 06	13.2, 14.8	14 43.2 E					36		G II
			Jan 24, 06	10.2, 12.3, 13.6	14 44.8 E			10.8, 11.8	.27714	36		G II
			Jan 29, 06	10.8, 14.6	14 44.6 E			11.8, 13.9	.27726	36		G II
			Feb 24, 06	10.1, 14.6	14 41.6 E			10.4, 14.1	.27678	36		G II
			Oct 25, 06			16.4	58 05.8 N				178.1256	G II
			Oct 27, 06	10.0, 11.5	14 45.8 E			10.4, 11.2	.27682	36		G II
			Oct 27, 06	13.4, 14.7	14 45.4 E			13.7, 14.3	.27702	36		G II
			Dec 5 to Dec 11, 06			Various(8)	58 06.0 N				35.12 & 178.1256	G II
			Dec 17, 06	15.7, 16.6	14 47.2 E					1		G III
San Diego, *Secondary*	32 40.8 N	242 47	Dec 5 to Dec 8, 06	Various(6)	14 46.6 E	Various(6)	58 06.3 N			*35 & 178*	35.12 & 178.1256	G III

SOUTH AMERICA.

PERU.

Station	Latitude	Long. East of Gr.	Date	Declination L. M. T.	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
San Lorenzo Island	12 05.3 S	282 46	Mar 14,'08	12.0, 14.0	9 17.6 E	16.6	3 27.8 S	12.6, 13.5	.29894	4	178.12	G III
			Mar 16, 08			11.3	3 26.9 S				178.12	G III
			Mar 17, 08	10.3, 11.4	9 16.8 E			10.9	.29915	4		G III
San Lorenzo Island, *8*	12 05.3 S	282 46	Mar 13, 08			12.5, 13.4	3 16.0 S				178.12	G III
			Mar 13, 08			15.6 (wt. ½)	3 10.9 S				169.12	G III
			Mar 14, 08	15.4, 16.4	9 19.6 E			15.9	.29866	4		G III

[1] Presidio station reported in 1916 as no longer suitable. The preferable station is Goat Island, in San Francisco Bay, which was reoccupied by the *Carnegie* party in 1916.

ISLANDS, PACIFIC OCEAN.

CAROLINE ISLAND.

Station	Latitude	Long. East of Gr.	Date	Declination Local Mean Time	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value	Instruments Mag'r	Instruments Dip Circle
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.		
Yap Island	9 31.4 N	138 12	Apr 17,'07	12.0, 13.0	2 03.4 E	16.9	6 15.5 N	12.3, 12.7	.36816	1	35.12
			Apr 17, 07	14.4	2 01.1 E					*35*	
			Apr 18, 07	12.6	2 02.9 E	10.3	6 10.0 N			*35*	178.12
			Apr 18, 07			13.5, 14.9	6 08.9 N				35.12
			Apr 18, 07			15.6	6 05.2 N				35.12
Yap Island, *W*	9 31.4 N	138 12	Apr 16, 07	11.4	2 03.7 E	14.7	6 12.7 N			1	178.12
			Apr 17, 07	6.6	2 04.2 E	10.4	6 11.5 N			*35*	35.12
			Apr 17, 07			12.9	6 08.8 N				169.12
			Apr 18, 07			10.3	6 09.2 N				169.12
Yap Island, *E*	9 31.4 N	138 12	Apr 16, 07	11.9, 12.6, 13.3	2 04.9 E			14.5, 15.0	.36744	1	
			Apr 17, 07			12.3	6 08.1 N				178.12
			Apr 18, 07	9.5, 10.4	2 06.2 E	16.4	6 09.8 N	9.7, 10.1	.36771	1	169.12

FANNING ISLAND.

Station	Latitude	Long. East of Gr.	Date	Declination Local Mean Time	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value	Instruments Mag'r	Instruments Dip Circle
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.		
Fanning Island	3 54.5 N	200 37	Oct 11,'05	10.4, 12.2	7 39.5 E	15.7	10 47.2 N	10.8, 11.8	.34124	36	171.12
			Apr 2, 06	14.1, 15.8	7 43.8 E			14.6, 15.4	.34087	36	
			Apr 3, 06	14.6, 16.2	7 44.4 E			15.0, 15.8	.34093	36	
			Apr 5, 06			12.4	10 45.6 N				178.12
Fanning Island, *Secondary*	3 54.5 N	200 37	Apr 2, 06			16.8	10 49.4 N				178.12
			Apr 3, 06			13.4	10 48.6 N				178.12
			Apr 5, 06	10.3, 14.5	7 43.7 E			10.8, 14.2	.34100	36	

FIJI ISLANDS.

Station	Latitude	Long. East of Gr.	Date	Declination Local Mean Time	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value	Instruments Mag'r	Instruments Dip Circle
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.		
Suva Vou	18 07.1 S	178 25	May 20,'06	11.0, 12.6	10 28.4 E			11.3, 12.3	.34868	36	
Suva Vou, *B*	18 07.1 S	178 25	May 20, 06			11.4	38 04.9 S				171.12

HAWAIIAN ISLANDS.

Station	Latitude	Long. East of Gr.	Date	Declination Local Mean Time	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value	Instruments Mag'r	Instruments Dip Circle
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.		
Sisal, *Honolulu Magnetic Observatory.*	21 19.2 N	201 56	Sep 19,'05	9.0, 11.0	9 23.4 E	14.3	40 04.2 N	9.6, 10.6	.29176	36	169.12
			Sep 19, 05			15.4 (wt.2)	40 08.2 N				171.12
			Sep 21, 05			10.5	40 02.0 N				169.12
			Nov 8, 05			13.9, 15.4	40 05.0 N				169.12
			Sep 3, 07			16.0	40 00.7 N				169.12
			Sep 4, 07	13.9, 15.6	9 22.9 E	14.0	40 01.7 N	14.7, 16.4	.29163	4	169.12
			Sep 6, 07	10.0, 13.4, 15.0	9 25.6 E			10.8, 14.1	.29163	4	
			Sep 7, 07	9.5, 11.1, 14.7	9 23.9 E			10.1, 13.9	.29172	4	
			Sep 9, 07					11.2, 13.7	.29176	4	
Sisal, *A*	21 19.2 N	201 56	Sep 3, 07			14.4 (wt.½)	39 55.7 N				189.56
			Sep 4, 07			8.9 (wt.½)	40 00.3 N				169.12
			Sep 5, 07	10.3, 14.5, 16.1	9 25.1 E	9.0, 15.3	39 57.6 N	11.1, 13.9	.29167	4	178.12
			Sep 6, 07			8.9, 15.8	39 56.8 N				178.12
			Sep 9, 07	13.1, 14.5	9 23.2 E					4	
Sisal, *B*	21 19.2 N	201 56	Sep 4, 07			15.8	39 55.8 N				189.56
			Sep 6, 07			10.7, 13.8	39 55.0 N				189.56

MARIANAS.

Station	Latitude	Long. East of Gr.	Date	Declination Local Mean Time	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value	Instruments Mag'r	Instruments Dip Circle
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.		
Guam, Cabras Island	13 28 N	144 40	Jul 16,'06	10.8, 12.6	2 14.8 E	14.4	14 15.0 N	11.5, 12.3	.34990	36	178.56
Guam, Cabras Island, *Secondary*	13 28 N	144 40	Jul 16, 06			11.1	14 20.9 N				35.25
Guam, Orote Point	13 27 N	144 37	Jul 17, 06	10.7, 12.0	2 11.6 E	14.3	14 14.7 N	11.0, 11.7	.35007	36	178.56
			Jul 19, 06			10.7 (wt.½)	14 16.0 N				35.25
Guam, Orote Point, *Secondary*	13 27 N	144 37	Jul 17, 06			11.4 (wt.½)	14 18.4 N				35.25
			Jul 19, 06	9.9, 11.3	2 11.1 E	14.0	14 14.8 N	10.3, 11.0	.35028	36	178.56

ISLANDS, PACIFIC OCEAN.

MARQUESAS ISLANDS.

Station	Latitude	Long. East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Nukahiva Island, S[a]	8 54 S	219 55	Jan 19,'07	10.4, 11.8	8 13.4 E	15.1	13 34.8 S	10.8, 11.4	.34222	1	178.12	G III
			Jan 21, 07	....	....	11.1, 14.4	13 35.8 S	....	....	......	35.12	G III
Nukahiva Island, S_1[a]	8 54 S	219 55	Jan 19, 07	14.9, 16.0	8 21.2 E	13.0	14 38.7 S	15.3, 15.7	.34444	1	178.12	G III
Nukahiva Island, S_2[a]	8 54 S	219 55	Jan 19, 07	14.2, 12.4	7 20.0 E	10.7	15 28.6 S	13.0, 13.8	.33460	1	178.12	G III
Nukahiva Island, S	8 54 S	219 54	Jan 23, 07	11.0, 12.4	8 19.0 E	15.6	15 19.4 S	11.4, 12.0	.33505	1	178.12	G III
			Jan 23, 07	13.2, 14.4	8 19.9 E	....	....	13.6, 14.1	.33468	1	....	G III
Nukahiva Island, S_1	8 54 S	219 54	Jan 22, 07	11.0, 11.5	8 18.7 E	....	....	....	....	1	....	G III
Nukahiva Island, S_2	8 54 S	219 54	Jan 22, 07	12.3	8 20.6 E	....	....	....	....	1	....	G III

MARSHALL ISLANDS.

Station	Latitude	Long. East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Jaluit Island	5 54.4 N	169 39	Jun 22,'06	10.5, 10.8, 12.9	8 17.1 E	....	....	11.4, 12.2	.34421	36	....	G II
			Jun 25, 06	....	....	10.8, 15.0	6 11.0 N	....	....	......	35.25	G II
			Jun 26, 06	....	....	14.5	6 11.0 N	....	....	......	178.56	G II
			Oct 23, 07	13.8, 16.2	8 15.4 E	16.7	6 11.0 N	14.9....	.34374	4	178.12	G III
			Oct 24, 07	14.5, 16.8	8 16.6 E	15.0, 16.4	6 05.6 N	15.2, 16.3	.34397	4	169.12	G III
			Oct 25, 07	....	....	14.9	6 05.1 N	....	....	......	169.12	G III
Jaluit Island, *Secondary*	5 54.4 N	169 39	Jun 22, 06	....	....	15.6	6 14.0 N	....	....	......	178.12	G II
			Jun 25, 06	11.4, 15.5	8 17.4 E	....	....	14.1, 15.0	.34448	36	....	G II
			Jun 29, 06	....	....	8.9	6 13.1 N	....	....	......	35.25	G II
Jaluit Island, *Secondary 2*	5 54.4 N	169 39	Oct 23, 07	14.1	8 13.9 E	11.4, 13.1	6 09.2 N	....	....	*178*	178.12	G III
Jaluit Island, *III*	5 52.9 N	169 36	Jun 29, 06	10.0	8 21.4 E	....	....	10.4	.34664	36	....	G II
Jaluit Island, *III*, *Secondary*	5 52.9 N	169 36	Jun 29, 06	....	....	10.4	6 08.4 N	....	....	......	178.6	G II

SAMOAN ISLANDS.

Station	Latitude	Long. East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Apia, *Observatory*	13 48.4 S	188 14	May 3,'06	8.6, 10.5	9 36.5 E	17.0	29 16.1 S[b]	9.0, 10.0	.35699	36	171.12	G II
			May 4, 06	....	....	8.2	29 13.9 S[b]	....	....	......	171.12	G II
			May 8, 06	....	....	9.5	29 12.6 S[b]	....	....	......	171.12	G II
Apia, *North Pier*	13 48.4 S	188 14	May 3, 06	....	....	9.0, 16.9	29 15.6 S	....	....	......	178.1256	G II
			May 4, 06	....	....	8.4, 9.4	29 14.4 S	....	....	......	178.1256	G II
Apia, *East Pier*	13 48.4 S	188 14	May 3, 06	....	....	8.8, 15.9	29 13.4 S	....	....	......	35.25	G II
			May 4, 06	....	....	8.5	29 14.8 S	....	....	......	35.25	G II
			May 4, 06	....	....	16.1, 17.2	29 12.7 S	....	....	......	178.1256	G II
Apia, *Stump*	13 48.4 S	188 14	Mar 5, 07	....	....	11.8, 12.6	29 16.2 S	....	....	......	178.12	G III
			Mar 6, 07	10.8, 11.8	9 36.0 E	14.4	29 16.4 S	11.1, 11.5	.35632	1	178.12	G III
			Mar 6, 07	....	....	15.9, 17.2	29 15.0 S	....	....	......	35.12	G III
			Mar 7, 07	14.6, 15.6	9 38.0 E	11.8	29 15.6 S	14.9, 15.3	.35678	1	178.12	G III
			Mar 7, 07	....	....	13.6	29 13.4 S	....	....	......	35.12	G III
			Mar 7, 07	....	....	9.6, 10.8	29 12.7 S	....	....	......	169.12	G III
Apia, *West Pier*	13 48.4 S	188 14	Mar 5, 07	13.6, 14.6	9 33.2 E	11.4	29 12.2 S	13.9, 14.3	.35636	1	35.12	G III
			Mar 5, 07	....	....	15.9	29 11.0 S	....	....	......	169.12	G III
			Mar 5, 07	....	....	17.1	29 15.4 S	....	....	......	178.12	G III
			Mar 6, 07	8.3, 15.1	9 42.9 E	9.1	29 16.3 S	....	....	*35*	169.12	G III
			Mar 7, 07	....	....	14.5	29 15.3 S	....	....	......	169.12	G III

[a]Local disturbance.

[b]These values have been increased numerically by 4′ on account of artificial disturbance: the value of the correction was given by Dr. Angenheister, of the Apia Observatory.

ISLANDS, PACIFIC OCEAN.

Society Islands.

Station	Latitude	Long. East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.		
Motu Uta*	17 32.6 S	210 26	Feb 6, '07	9.5	9 46.1 E					1	
Motu Uta, 1*	17 32.6 S	210 26	Feb 6, '07	11.6	9 58.9 E			11.5	[illegible]	1	
Papeete*	17 32.6 S	210 27	Feb 2, '07	10.6, 12.1	7 40.2 E	14.1	28 22.3 S	11.1, 11.5	[illegible]	1	178.12
Papeete, Secondary*	17 32.6 S	210 27	Feb 2, '07	13.2, 14.6	7 58.8 E	11.7	29 45.4 S	13.6, 14.3	[illegible]	1	178.12
Small Coral Island*	17 32 S	210 25	Feb 6, '07	15.2	9 37.3 E					1	
			Feb 7, '07	11.1	9 28.1 E	14.5	29 25.6 S			1	178.12
			Feb 8, '07			11.5	29 25.5 S				180.12
			Feb 8, '07			14.3	29 25.9 S				35.12
			Feb 11, '07			10.6, 12.6	29 22.5 S				180.12
			Feb 11, '07			13.7	29 28.2 S				180.12
			Feb 12, '07	11.4, 12.7	9 40.7 E			11.8, 12.4	[illegible]	1	
Small Coral Island, 1*	17 32 S	210 25	Feb 6, '07	15.5	9 30.1 E					1	
			Feb 7, '07			9.6	29 24.4 S				178.12
Small Coral Island, 2*	17 32 S	210 25	Feb 6, '07	16.2	9 30.8 E					1	
			Feb 7, '07			11.4	29 24.5 S				178.12
			Feb 8, '07			10.8, 12.2	29 19.6 S				35.12
			Feb 8, '07			14.2	29 28.0 S				180.12
			Feb 9, '07			10.6, 13.5	29 20.5 S				35.12
			Feb 9, '07			14.5	29 32.3 S				180.12
			Feb 12, '07	14.8, 16.1	9 41.3 E			15.2, 15.5	[illegible]	1	

*Local disturbance.

DESCRIPTIONS OF SHORE STATIONS, 1905–1916.

One of the chief difficulties experienced by the observers of the Department of Terrestrial Magnetism in the reoccupation of old stations for secular-variation data has been the lack of information necessary to precise recovery of the point where the previous observations were made. Owing to the frequent occurrence of local disturbances, it may readily happen that erroneous secular-variation data will result from non-recovery of exact station. Accordingly the observers of the Department are instructed to furnish as complete descriptions as possible of stations occupied, especially of such as give promise of future availability. Information additional to that contained in the published descriptions or copies of station-sketches or of photographs of surroundings will gladly be given to those interested in the reoccupation of any of the stations.

The descriptions are given in alphabetical order under the same geographical divisions adopted in the preceding table of shore results. The general form followed in the descriptions is: Name of station, year when occupied, general location, detailed location, distances and references to surrounding objects, manner of marking, and finally the true bearings of prominent objects likely to be of permanent character. All bearings, unless specifically stated otherwise, are true ones, and are reckoned continuously from 0° to 360°, in the direction, south, west, north, east. When no mention is made of marking of station, it is to be understood that the station was either not marked at all or not in a permanent manner.

Most of the measured distances were made originally in the English system; however, the distances obtained by conversion into the metric system are also

given, but inclosed in parentheses, so as to show that they are converted figures. The following rules have been adopted in the conversions: distances given to 0.01 foot are converted to the nearest 0.001 meter, 0.1 foot to the nearest 0.01 meter, 1 foot to the nearest 0.1 meter, estimated feet or yards to nearest meter, estimated fraction of a mile to nearest 0.1 kilometer, and estimations of more than a mile to nearest kilometer. Short and important reference distances, when measured accurately, have been converted into nearest 0.1 centimeter; such measurements, however, as, for example, dimensions of marking-stones, etc., which are not of great importance, have been converted to the nearest centimeter. If a distance is given immediately preceding an azimuth of a mark, it is to be interpreted as distance from the magnetic station to the mark.

ASIA.

China.

Woosung, Kiangsu, 1907.—Two main stations were established. Station *12* is on left bank of Woosung River, about 1 mile (1.6 kilometers) above harbor master's quarters and the tidal semaphore; about 4 feet (1.2 meters) above ordinary high water, about 34 feet (10.4 meters) from water's edge at high water, and 130 feet (40 meters) from earth embankment that extends along river; marked by a pine stake about 5½ inches (14 cm.) square and about 40 inches (about 102 cm.) long. The following true bearings were determined: station Woosung *13*, 180° 08′.1; tidal semaphore, 128°25′.7.

Two auxiliary stations to *12* were occupied and designated as 12_M and 12_N, being 27 feet (8.2 meters) and 51 feet (15.5 meters) respectively from *12* in true azimuth line 130° 34′.9.

Station Woosung *13* is on right bank of Woosung River, almost due north across the river from station *12*, and distant about 1 mile (1.6 kilometers); on a high grassy bank, which forms the north side of a small inlet, and is about 300 feet (91 meters) north of large sign which reads "Telegraph cables across the channel here"; marked by a large tent peg. The following true bearings were determined: the tidal semaphore, 65° 58′.6; upper limit anchorage beacon, 338° 43′.0.

Zikawei, Kiangsu, 1907.—Observations were made in the magnetic hut used for absolute observations, also at station *N*, 21.3 meters north 6° west of pier in hut.

Japan.

Kisarasu, Tokaido, 1906.—On east shore of Tokio Bay, in the village, in an open space near the landing wharves, 38.5 feet (11.73 meters) east of the sea wall; marked by a wooden peg. A secondary station is about 50 feet (15 meters) north of principal station.

Sugita, Tokaido, 1906.—On west shore of Tokio Bay, in village of Sugita, on a small inlet known as Mississippi Bay. It is in an old garden about 15 feet (4.5 meters) from the open shore and about 75 feet (23 meters) from road running through Sugita to Yokohama. Observations were also made at a secondary station about 60 feet (18 meters) southwest of principal station.

Tokio, Tokaido, 1906.—On grounds of the Tokio Imperial University at a point about 30 feet (9 meters) north of the magnetic house in playgrounds of the university and in line with lightning rod on Science Hall, the true bearing of which, as furnished by Dr. Tanakadate of the university, is 179° 54′.6; marked by wooden peg. A secondary station is about 30 feet (9 meters) west of principal station.

AUSTRALASIA.

New Zealand.

Christchurch, South Island, 1907-08.—The observations were made at absolute house of observatory. Secondary stations, designated as *brass pipe*, *peg A*, and *near brass pipe*, were also occupied. The first is about 150 feet (46 meters) northeast of absolute house; the second is about 40 feet (12 meters) north-northeast of absolute house; the third is somewhat east-southeast of *brass pipe*.

New Brighton Beach, South Island, 1908.—Station is about 1,500 yards (1.4 kilometers) south of the recreation pier; on the beach just above high water, about 24 paces from edge of vegetation, between the sandhills and the sea. The point was roughly marked subsequently by a post 4 by 4 inches by 8 feet (12 by 12 cm. by 2.4 meters). The lighthouse is in true bearing 323° 15′.1.

NORTH AMERICA.

United States.

Baldwin, Kansas, 1905, 1906.—Observations were made at the absolute magnetic observatory of the United States Coast and Geodetic Survey. The true bearing of flagpole on Science Hall is 131° 39′.4. At the end of 1906 a secondary station, designated as *tent*, was occupied at a point about 50 feet (15 meters) from the absolute observatory, in line with flagpole on Science Hall of Baker University.

Berkeley, California, 1905.—The station of the U. S. Coast and Geodetic Survey of 1904, on the grounds of the University of California, was reoccupied. It is west of and in line with the north face of South Hall, 261.5 feet (79.7 meters) from its northwest corner, 31 feet (9.4 meters) west of center of path leading from gymnasium to North Hall, 46 feet (14.0 meters) north of the path leading from South Hall to Center Street entrance to the grounds, and 54 feet (16.5 meters) from edge of driveway; marked by a granite post 8 by 8 by 24 inches (20 by 20 by 60 cm.) set flush with ground and lettered U. S. C. & G. S. The following true bearings have been determined: west edge of gymnasium just above porch, 44° 34′.4; northwest edge of North Hall, 194° 46′.1.

Goat Island, San Francisco Bay, California, 1905, 1908.—U. S. Coast and Geodetic Survey station of 1904. It is on a military reservation of the United States Government near the center of the plateau just west of the hill at the extreme eastern end of the island, is nearly in line with the top of the hill and the smoke-stack at the naval training station, and about 50 feet (15 meters) north of the line of the wireless mast on highest part of island, and the flagpole on the southern

NORTH AMERICA.

UNITED STATES—*continued.*

part of the lawn in front of the officers' quarters; marked by small hole in top of a rough stone 6 by 6 by 12 inches (15 by 15 by 30 cm.) with a flat top which projects slightly above the general surface. In 1908 three secondary stations were established. The first is 74 feet (22.6 meters) true north 56° 08′ east of main station. The second and third, used for ship instruments, were about 45 feet (14 meters) west of and 35 feet (11 meters) northwest of main station, respectively. [Main station reoccupied in 1916.]

Kutkan Island, Alaska, 1907.—On the eastern point of land on Kutkan Island, 30 feet (9 meters) from the water's edge, at high tide, on the north side, 12 feet (4 meters) on the south side, and 50 feet (15 meters) from extreme eastern edge of island. A cross, cut in the top of a large irregular rock projecting about a foot above ground, marks the exact spot. The following true bearings were determined: pier at Sitka absolute magnetic observatory, 156° 49′.3; U. S. Marine Corps barracks flagstaff, 148° 51′.2; Mission flagstaff, 187° 33′.1.

San Diego, California, 1905, 1906.—Five stations were established here; these are designated as San Diego *I*, *Secondary*, *II*, *III*, and *C. & G. S., 1897.*

The first, San Diego *I*, is near the northern point of North Coronado Beach Island; near the shore of the bay, facing the city, about 320 paces west of the west corner of engine house of Marine Railway (Spreckels) and 58 paces from road that runs along the beach. Beacon No. 10 bears approximately north-northwest from the station, which is marked by a spruce post, 6 by 6 by 50 inches (15 by 15 by 127 cm.) set with its faces approximately with the cardinal points and projecting about 1 foot (30 cm.) above the surface; the letters C. I. are cut on the north face and 1905 on the south face. The following true bearings were determined: School of Theosophy, 96° 47′.8; stand pipe, 187° 54′.2; flagpole on south tower of Coronado Hotel, 338° 38′.4. A secondary station, designated as *Secondary*, was established 50 feet (15.2 meters) south-southeastward in the line toward the Coronado Hotel from San Diego *I*.

San Diego *II* is on the northwest portion of North Coronado Beach Island, about midway between the C. & G. S. station at Quarantine and Station I; about 75 yards (69 meters) from the northwest beach of North Coronado Beach Island, and in the line joining Harbor Beacon No. 2 and the south end of the most southerly building on Quarantine Wharf; marked by a redwood post 4 by 6 by 44 inches (10 by 15 by 112 cm.) projecting about 8 inches (20 cm.) above ground. The letters C.I. and the numeral II are cut on the two faces which face the north and south respectively. The following true bearings were determined: south tower of Coronado Hotel, 306° 40′.8; old lighthouse, Point Loma, 33° 37′.7; central dome, School of Theosophy, 117° 28′.1.

San Diego *III* is on the north shore of San Diego Bay, on a low beach northwest of Dutch Flat, and about 100 yards (91 meters) north 25° east of a triangulation signal on the sand spit; marked by redwood post 4 by 6 by 52 inches (10 by 15 by 132 cm.) extending about 10 inches (25 cm.) above ground and having the letters C. I. cut in the north face, and a hole near the center of the top. The following true bearings were determined: south tower of Coronado Hotel, 337° 19′.7; old lighthouse, Point Loma, 24° 08′.1; School of Theosophy, 63° 28′.1.

The C. & G. S. 1897 station, occupied in 1905, is that established by the Coast and Geodetic Survey in 1897. It is in the northeast portion of the city, about 150 feet (46 meters) southwest of where Seventh and Fir streets would intersect if extended into the park; marked by redwood post 4 by 4 by 36 inches (10 by 10 by 91 cm.) projecting about 1 foot (0.3 meter) out of ground, lettered U. S. MAG. and 1897 on its north and west vertical faces respectively.

San Francisco, Presidio, California, 1905.—The station of the U. S. Coast and Geodetic Survey of 1904, at the triangulation station on Presidio Hill, northwest of gate on south side of Presidio grounds at the edge of the woods, was reoccupied; marked by stone post 6 inches (15 cm.) square on top, projecting 6 inches (15 cm.) above ground and lettered on top U. S. C. & G. Survey, 1881. The following true bearings have been determined; cross on Lone Mountain, 325° 53′.8; center of top of Drake Cross, 27° 03′.7. [This station reported in 1916 as no longer suitable. A 6 million gallon reservoir is now on the site.]

San Rafael, California, 1905, 1908.—There are three stations, two being those of the U. S. Coast and Geodetic Survey of 1897. They are 1.1 miles (1.8 kilometers) northwestward from the county courthouse, on the eastern slope and near the top of a hill, about 375 feet (115 meters) distant from one of the water company's reservoirs. There is a meridian line marked by two marble posts 8 by 8 by 48 inches (20 by 20 by 122 cm.) projecting about 24 inches (61 cm.) above the surface of the ground; the north stone is lettered U. S. C. & G. S. on its west vertical face, MAG. STA. on the south face, and 1897 on the east face, and bears a cross on its upper face marking the exact point. The south stone is set about 2,300 feet (701 meters) true south of the station, its north vertical face being lettered MER. MARK., the east face U. S. C. & G. S., and the west face 1897.

In 1897, 1905, and 1908, dip-circle observations were made at a point, designated as *Dip Station*, 50 feet (15 meters) from the north stone, and magnetometer observations were made at a point, designated as *Magnetometer Station*, 10 feet (3.0 meters) from the north stone in the extension of the line from flagstaff on the county courthouse to the north stone. In 1908 observations were also made over the north pier. The flagpole on county courthouse is in true bearing 289° 46′.0.

Sitka, Alaska, 1907.—Two stations occupied; the principal pier in the Sitka auxiliary magnetic observatory of U. S. Coast and Geodetic Survey, and in the regular absolute house.

SOUTH AMERICA.

PERU.

San Lorenzo Island (Callao Harbor), Lima, 1908.—The main station is about 5.5 feet (1.7 meters) above and about 50 feet (15 meters) distant from the ordinary high-water mark on the beach, and is approximately the U. S. Coast and Geodetic Survey station of 1907. It is 79 feet (24.1 meters) and 67.4 feet (20.54 meters) from the northeast and southeast corners of the powder magazine (marked "Deposito de explosivos"), which are in true bearing north 68°.7 west and south 34°.1 west respectively, and 57.5 feet (17.5 meters) from door of magazine directly beneath flagstaff. The point is marked by a small round stake driven flush with ground. The following true bearings were determined: square tower with clock in Callao, 250° 31′.0; spire of church on point in Callao, 256° 00′.7. A secondary station designated as San Lorenzo Island *2* was established at a point south 31° east true 52.5 feet (16.0 meters) distant from main station.

ISLANDS, PACIFIC OCEAN.

CAROLINE ISLANDS.

Yap Island, 1907.—The main station is on northwestern point of islet "Tarrang," near upper end of Tomil Bay, in Port Tomil, about 100 feet (30.5 meters) from the west and about 500 feet (152 meters) from the northwest shore lines of the islet, and 55 feet (16.8 meters) northwest of a large tree. Marked by a pine post 5½ by 5½ by 40 inches (14 by 14 by 100 cm.) set so as to project about 16 inches (40 cm.) above general surface; the lower part of post is tarred and the upper part painted white, with C. I. marked on one side and 1907 on the opposite side; the precise point is indicated by a cross cut in head of a brass screw set in center of top of post. The following true bearings were determined: beacon on Buray Hill, 88° 38′.2; chimney on west gable of long white cable building, 30° 00′.5. Two secondary stations were established, designated as Yap *W* and Yap *E*, the first 39.6 feet (12.08 meters) west of the main station, and the second 40.1 feet (12.23 meters) east of the main station; both secondary stations are in range with the principal station and the harbor beacon. From Yap *E* the windmill at cable station is in true bearing 44° 37′.2.

FANNING ISLAND.

Fanning Island, 1905, 1906.—The main station is on a sandy plain east of cable station and near shore of lagoon, 105 feet (32.0 meters) west of rear of boat house on shore of lagoon and in line with quarters building at cable station. Marked by a redwood post 4 by 4 inches (10 by 10 cm.) in cross-section and 40 inches (102 cm.) in length, set so as to project about 1 foot above general surface; small hole in top of post marks the precise point. The following true bearings were determined: flagstaff at cable station, 94° 16′; center rod of windmill, 102° 49′.3. A secondary station was established in 1906 at a point about 100 feet (30 meters) true north 55° 52′ west of the main station.

FIJI ISLANDS.

Suva Vou, Viti Levu Island, 1906.—About 2 miles (3 kilometers) from Suva, on north shore of Suva Harbor and on a point called Suva Vou, identical with H. M. S. *Waterwitch* station of 1896 and was found marked by a concrete post standing about 18 inches (45 cm.) out of ground. The post is marked with an arrow and the year 1896. The lower lighthouse is in true bearing 129° 48′.6. A secondary station for dip observations, and designated as Suva Vou *B*, was established about 75 feet (23 meters) northeast of above station.

HAWAIIAN ISLANDS.

Sisal (Honolulu Magnetic Observatory), Oahu Island, 1905, 1907.—The observations were made on the magnetometer pier of the absolute house of the Coast and Geodetic Survey magnetic observatory, located at Sisal. In 1907 a tent station, *A*, was also occupied about 40 feet (12 meters) due true north of the absolute observatory pier, in the observatory inclosure. A second tent station, *B*, was established about 60 feet (18 meters) southwest of the absolute observatory, in observatory inclosure. The various ship instruments were tested in 1907 at several other points in the observatory grounds.

MARIANAS.

Guam, 1906.—Four stations were established, two at Orote Point and two at Cabras Island. The main station at Orote Point is east of the Point, on the south side of Apra Harbor, and on a sand beach near base of high land on outer edge of vegetation. Marked by a cement post, set with its top somewhat above surface of ground. The following true bearings were determined: flagpole at Piti, 256° 39′.1; wireless telegraph pole, 266° 03′.6. Observations were also made at a point, designated Orote *Secondary*, about 30 feet (9 meters) east-northeast of the main station. The main station on Cabras Island is on the north side of Apra harbor, approximately 150 yards (140 meters) west of coal shed and about 30 feet (9 meters) from water. The following true bearings were determined: flagpole at cable station, 41° 09′.4; magnetic station at Orote Point, 71° 07′.0. Observations were also made at a point, designated Cabras *Secondary*, about 50 feet (15 meters) west of principal station.

MARQUESAS ISLANDS.

Nukahiva Island, 1907.—A number of stations were occupied and indicated local disturbance. Station *8* is on the site of the old Fort Collet, a small, conspicuous rocky knoll on east side of Tai-o-hae, or Anna Maria Bay, and about 90 feet (27.5 meters) above sea-level. The point is about 40 feet (12 meters) northwest of a trail which leads up from the public trail to the harbor light, which is fixed to a pole 57.8 feet (17.63 meters) distant. Marked by a hole in the top of a pine post 3.5 by 5.5 by 33 inches (10 by 14 by 84 cm.) set one-half its length in the ground. The harbor light is in true bearing 0° 40′ west of south. Station *9* is near the northwest head of Tai-o-hae, or Anna Maria Bay, on land covered with a dense growth of tall brush, belonging to the government. This point is 27 feet (8.2 meters) distant from and about 3 feet (1 meter) above high-water mark. The station is marked by a hole in top of a pine post 3.5 by 3.5 by 44 inches (9 by 9 by 110 cm.) projecting about 40 cm. above the ground. Three test stations were also established at points around *9*; they are designated as 9_1, 9_2, and 9_3. The following true bearings were determined from *9*: station *8*, 278° 42′.3; harbor light pole, 279° 07′.6; northwest edge of Government House, 274° 00′.4. Two additional stations were placed on the line determined by station *8* and the basaltic cliff, which is in true bearing 60° 29′.1 west of south from *8*. The first, designated as 8_1, is 40 feet (12.2 meters) west, and the second, 8_2, is 43 feet (13.1 meters) east along this line from the principal station.

MARSHALL ISLANDS.

Jaluit Island, 1906, 1907.—The main station of 1906 and 1907 is at American Town, about one and one-fourth miles (2 kilometers) south of the settlement, near the high-water mark and the shore end of the old railroad pier. Marked by a cement post bearing the letters C.I. 1906, set with its top slightly above the surface of the ground. The following true bearings were determined: Company's flagpole, 204° 17′.2; hotel flagstaff, 197° 38′.4; beacon in lagoon, 183° 31′.8. Observations were also made in 1906 at a point, designated as Jaluit *Secondary*, about 30 feet (9 meters) to the south and in range with station and Company's flagpole. Station Jaluit *III* of 1906 was established to test local disturbance about the position of swing in harbor, and is about 3 miles (5 kilometers) southwest of the principal station. Dip observations were made at a point, *III Secondary*, about 75 feet (22.9 meters) east of *III*. In 1907 a secondary station, designated Jaluit *Secondary 2*, was established at a point 57.8 feet (17.62 meters) true south 17° 38′ west of the main station.

ISLANDS, PACIFIC OCEAN.

SAMOAN ISLANDS.

Apia, Upolu Island, 1905, 1906, 1907.—The observations made by G. Heimbrod in 1906 were at the first absolute house, on the spit of land called Mulinum, of the Samoa Observatory of the Imperial Academy of Sciences of Göttingen. The observations of 1906 by the officers of the *Galilee* were made at three points. One of these was the first absolute house of the Samoa Observatory. The second station, designated *North Pier*, was in the observatory grounds about 50 feet (15 meters) north of the absolute house. The third station, designated as *East Pier*, was in the observatory grounds about 50 feet (15 meters) east of the absolute house. The observations in 1907 were made at two stations. The first, designated *Stump*, was near the north pier station of 1906, being about 10 feet (3 meters) northwest of the north pier. The second, designated as *West Pier*, was in the observatory grounds about 41 feet (12.5 meters) west from west wall of new absolute house. The first absolute house of the observatory was being rebuilt at the time of the 1907 work and it was not possible to observe in it.

SOCIETY ISLANDS.

Motu Uta, Tahiti Island, 1907.—Three stations were occupied near southeast corner of small island called Motu Uta in Papeete Harbor and designated as Motu Uta, Motu Uta *1*, and Motu Uta *2*. They are in line with flagstaff at Government Building. Motu Uta is the middle point, and stations *1* and *2* are 30 feet (9.1 meters) on each side, *2* being near the high-water mark. True bearing of cathedral spire from Motu Uta, 296° 59′.0. (Station Motu Uta *2* was used only as a test station for local disturbance, and all observations were incomplete and for that reason no results were given.)

Papeete, Tahiti Island, 1907.—Within and near eastern corner of a tract of government land immediately south of the Botanical Garden, approximately 350 feet (106 meters) southeast of gardener's house in Botanical Garden, 175 feet (52 meters) northeast from windmill pump on government tract, 73 feet (22.2 meters) south-southeast from a large coconut tree standing near the fence, and approximately 50 feet (15 meters) from the fences to east and south. Marked by a hardwood post, lettered on top T. M. C. I. and having a copper tack at the center. A secondary station was occupied 50 feet (15 meters) true north 32° 32′ west of the main station.

Small Coral Island (Papeete Harbor), Tahiti Island, 1907.—On a small sandbar, about 100 feet (30 meters) long, and the same in width, rising about a foot (30 cm.) above high water, situated south of entrance to Papeete Harbor. Marked by a fir post about 3½ inches (9 cm.) square and 4 feet (1.2 meters) long, sunk 1 foot (30 cm.) in the ground. The following true bearings were determined: Cathedral spire, 265° 57′.2; north obelisk, 267° 16′.8; south obelisk, 312° 04′.5. Two auxiliary stations, designated as *1* and *2*, were occupied on the west and east sides of and 30 feet (9.1 meters) distant from the principal station, in line with the cathedral.

EXTRACTS FROM DIRECTOR'S INSTRUCTIONS FOR CRUISES AND OBSERVATIONAL WORK ON THE GALILEE.

The following extracts from the Director's instructions and letters to those in command of the vessel will serve to explain the routes followed by the vessel and the methods of observation adopted for the various kinds of work. While some of the early methods, according to experience gained, were modified or superseded, their complete presentation here will be useful in showing how the observations were made at the successive stages of the work, and how the methods and instruments were gradually developed and improved. The comparison of instructions for observations aboard a magnetic ship with those for the work on a non-magnetic one (see pp. 316–324), will be of interest, and will show the great superiority of having a vessel specially adapted for the problem undertaken. The extracts form thus also an historical record of the experiences it was necessary to pass through before reaching the goal set.

When referring to "swings" of vessel, the term "first helm" is used, regardless whether vessel was swung first with starboard or with port helm. The term "other helm" signifies that the vessel was swung next with helm opposite to that used first. Thus, if for any series of swings, "first helm" is the starboard-helm swing then "other helm" is the port-helm swing.

CRUISE I OF THE GALILEE, 1905.

J. F. Pratt in Command.

From Instructions of Aug. 15, 1905, to J. F. Pratt, San Diego, Cal.

1. Upon completion of the necessary alterations on the *Galilee* you will proceed with her to Honolulu, Hawaii, thence work northward as far as the conditions will permit, returning once more to the Hawaiian Islands, if considered best, thence to the Midway Islands, and return to San Francisco[1] about December 1, 1905. (This is a general outline of the region to be covered, the precise manner of execution for the successful conduct of the work being left to your judgment.)

2. The necessary swings for the determination of the deviations in the declination, dip, and intensity will, of course, again be made at the time of departure from San Diego. (For the harbor swings, whenever possible, 16 equidistant headings[2] should be taken.) It is especially essential that, during these swings, all articles likely to affect the instruments be in same position as at sea. In this connection you are urged to pay special attention to the iron at the head of the sail when down on the boom, in which position it may come too close to the dip-circle position. In general, the same methods are to be pursued as at San Francisco, except that observations with sea deflectors are to be made as follows: First 8 points use magnet 45, letters on magnet up, next 8 points use magnet 45, letters down; for swing on other helm, use magnet NL, letters up, on 8 points, and then on remaining 8 points, letters down.[3] As much time as possible should be given on each heading, and the list, roll, and any other pertinent data be noted.

3. If not already done, deflection observations should be made ashore with magnets 45 and NL (letters up and down), so as to determine the constants anew. Likewise the times of oscillation of the two Kelvin cards, as at San Francisco, are to be obtained.

---

[1]Changed later to San Diego.
[2]Changed to 8 equidistant headings, experience having proved this number sufficient for the *Galilee*.
[3]Changed subsequently in accordance with footnote 2.

4. All observations made at San Diego, inclusive of the ship swings, are to be transmitted to Washington, so that the Office can make final reduction of the work done on the trip from San Francisco to San Diego. Abstracts of the essential quantities should be made in the "Abstract Books" left in your possession.

5. In general at sea, swings on as many points as possible are to be secured, on the average every second or third day, conditions permitting, and observations be made on the intermediate days on the ship's course, again using every precaution as to the position of articles likely to affect the instruments. In the sea-deflector work it is preferable to use each time both magnets as per general scheme above, not having, however, on the bridge more than one magnet at a time.

6. On the course observations.—Dip and intensity observations with sea dip-circle 169 (needles 1, 2, *3*, *4*), and observations with sea deflector 1 should be made according to method followed on experimental trip from San Francisco. It will be well to interchange observers. Thus first day: Dr. Egbert, sea deflector; Mr. Ault, sea dip-circle. Next day: Dr. Egbert, dip circle; Mr. Ault, deflector, etc. The endeavor should be to have the mean time of the deflector work about the same as that for the dip circle.

7. Should it not be possible to make deflections with the dip circle in low latitudes, then continue, nevertheless, the observation with the loaded needle, and thus secure relative total intensity. The observers must be cautioned to take every possible care in handling the needles. Should anything happen to needle No. 3, preventing its further use, then cable as soon as possible and substitute for it one of the dip needles (No. 1 or 2), noting that thereafter the particular dip needle selected can no longer be used for inclination observations, and must not have its magnetism disturbed; it should be kept in the box with No. 4. In case anything happens to the loaded needle (No. 4) so as to make impossible observations with it, then continue simply the deflections and inform the Office promptly of the accident. It is sincerely hoped, however, that these contingencies will not occur.

8. Owing to the difficulty in securing declinations, on account of meteorological conditions, it will be necessary to avail yourself of every opportunity to secure data, keeping a man on the lookout on the bridge whenever necessary. The observations should be made over as long an interval as possible, and it will suffice to get them, in general, with the Ritchie standard compass (R1A); however, it will not be amiss to secure comparative data with the other compasses, this being one of the purposes of the expedition.

9. The list, roll, and all other pertinent data must be entered in the record for all observations made.

10. The general investigation of local disturbances in the vicinity of land-masses must be left to your judgment, this matter being dependent on conditions encountered.

11. The various instrumental constants and ship deviation-coefficients will again be determined at Honolulu, Hawaii, making use of the facilities at the Coast and Geodetic Survey Magnetic Observatory, so as to check up once more on the instruments. They will also be determined again at San Francisco.[1]

12. All navigational data and geographic positions assigned to the observations at sea must be checked by some independent observer, besides the one to whom you will give chief charge of this work. * * *

FROM DIRECTIONS OF SEPTEMBER 18, 1905, TO J. F. PRATT, HONOLULU.

1. Judging from experience in the discussion of observations made on Coast and Geodetic Survey vessels, and that now being encountered on the *Galilee*, it would appear that our principal trouble on the latter vessel will arise from the shifting positions of masses of iron, as for example, hoisting-chains and blocks. There are several instances in our observations from San Francisco to San Diego where differences have occurred, which can only be explained by the circumstance that masses of iron may have come too close to the instruments.

2. You are therefore requested to make a study of the remaining masses of iron in the rigging, sails, and hoisting tackle, which could be replaced by non-magnetic metal, and to make an estimate of the probable cost, so that it may be decided whether the changes can be made when the *Galilee* returns to San Francisco (San Diego). A critical analysis of the observations thus far shows very clearly that if we can properly control the positions of the remaining masses of iron, a most gratifying

[1]Changed later to San Diego.

degree of accuracy in the determination of the magnetic elements may be obtained. * * * Certain observations on August 7 show very clearly that, between the inclination and the intensity observations, something occurred which caused a different distribution of iron masses within the region of influence. * * *

3. It is also extremely essential that the observer remove from his person all articles likely to affect the instruments, and it would be well to devise some form of statement to be entered in the report of the observations to insure that this has been done. * * *

FROM DIRECTIONS OF OCTOBER 16, 1905, TO J. F. PRATT, HONOLULU.

1. On the 12th instant, the following cablegram was sent you to Honolulu: "Daily swings necessary. Instrumental changes require closing San Diego instead San Francisco. Instead failing deflections observe usual dips. Acknowledge." * * *

2. We are having great difficulty, for one reason or another, making the deviations fit theory, and it is believed that the only safe course to follow is to *swing* every day,[1] so that the mean results will be free from uncertainty on account of deviation. It will be a great saving, especially in the computation, if we do not have to bother with deviations. With this experience in mind, please do your utmost to secure swings as often as possible. * * *

3. You will doubtless swing the *Galilee* off the coast near the Honolulu Magnetic Observatory, about where you swung the *Patterson*, of the Coast and Geodetic Survey, in 1904. The cablegram calls for dip observations in place of the deflections when they fail. * * *

FROM DIRECTIONS OF OCTOBER 17, 1905, TO J. F. PRATT, HONOLULU.

1. Before it is possible to reduce completely the observations from San Diego to Honolulu, it will be necessary to secure some good swings at Honolulu at the place mentioned in the letter of yesterday. At least two good swings are desired: for example, one a. m. and one p. m., to be repeated, if observations are not satisfactory. The inclination and intensity observations should be made thus: a. m., observations with loaded needle on first helm, next inclination observations with needle No. 1, say on the other helm swing; p. m., observations with loaded needle on helm opposite that of the morning; next inclination observations with needle No. 1 (polarities reversed) on other helm. It would be preferable if observations could be made on each heading for each of the positions of the circle (both for the loaded needle and the dip needle). Thus, the observations on each heading would be for the positions: face circle east; face needle east; face circle west; face needle west; etc.

2. Swings with dip needle and loaded needle should be kept up after leaving Honolulu until the deflection method becomes available again with the sea dip-circle, after which it will be desirable to alternate; for example, on one day swings with loaded needle and with dip needle, while on the next day, swings will be made with the loaded needle, followed by deflections.

3. At San Diego, the port of arrival, swings will be made, using both methods given in 2.

4. Inclination observations at the land station should hereafter be made regularly by the direct method, also with needle 3, not reversing polarities, however, in the latter case. It will therefore be necessary, before you leave Honolulu, to make such observations at the Honolulu Observatory in sufficient number to give a good value of the correction required to reduce the inclination thus obtained with No. 3 to the standard value. Whenever the deflection method is applicable, the inclination will likewise be obtained in this way, in order that the data may be derived for determining the corrections on account of non-reversal of polarity of deflected needle. * * *

FROM INSTRUCTIONS OF NOVEMBER 22, 1905, TO J. F. PRATT, SAN DIEGO, CAL.

1. In addition to the directions contained in the instructions of August 15, and letters of September 18 and October 16 and 17, respecting the closing work at San Diego, complete magnetic observations (D, H, I) at both C. I. W. shore stations Nos. I and III, between which the ship was swung last August, are to be made. At both of these stations, furthermore, standardization observations will be made with the dip circles, and the intensity constants will be determined for the sea dip-circle, and for the sea deflector.

[1]Owing to meteorological conditions encountered, this did not prove feasible.

2. All observations called for in paragraph 1 will be computed and revised immediately, and repeated, if necessary, before any change whatsoever is made in the ship or in the instruments. For your guidance, there is inclosed a tabulation of the previous results obtained. * * *

3. Please note that the swings at San Diego must be made under the same conditions of ship as at sea, as nearly as that can be attained, and that the same methods, *e. g.*, for azimuth, be used as for the sea observations; otherwise, the deviations obtained will not strictly apply. * * *

4. A complete tabulation of the corrections for all time-pieces on board must be forwarded to the Office, so that their behavior will be known. * * *

5. It would be extremely desirable, in order to improve the sea dip-circle and obviate the deflection method failing so quickly, that a rough determination be made of the distance at which deflections would be possible at the Honolulu Observatory.

6. If you have not covered the gimbal stand for the dip circle so as to shield the pendulum bob from the wind, please attend to this. Some of the outstanding effects on the dip circle apparently can not be ascribed to ship deviations, but rather to a want of level of the instrument, as might be caused, for example, by the action of the wind.

7. The complete analysis of the entire work also makes it desirable that the deviations for a compass placed at the dip-circle position be determined at one of your ports. This can be done by comparison, using, for example, the method followed with reference to the Kelvin compass at San Francisco.

8. Please request the observers to make a note on the dip sheet when they remagnetize the dip needle before beginning the observations, and to give the number of strokes used. * * *

FROM INSTRUCTIONS OF DECEMBER 18, 1905, TO J. F. PRATT, SAN DIEGO, CAL.

1. Before leaving San Diego, please make sure that all instructions sent you respecting the closing work at San Diego have been fully carried out, in order that there may be no difficulty in the final reduction of the observations. This is especially important in view of the contemplated changes.

2. You will of course see to it that all reports and records are complete, as called for in the various instructions before forwarding them to the office.

3. You will arrange, as offered, regarding the early completion of the additional alteration agreed upon, which, briefly stated, involve: (*a*) building a new galley over the forehatch; (*b*) cuttin off the after end of the old house, so as to leave about 8 feet for a forecastle; (*c*) extending the observin bridge; (*d*) changes in hoisting-gear so as to make it as non-magnetic as possible; (*e*) removal of iro strips around middle hatch; (*f*) building of an extra cabin.[1] (If binnacles and stands on the bridg are removed, their present places should be carefully marked, so that, if necessary, everything can b exactly replaced.) * * *

4. Since it has been arranged that the alterations will be supervised by Captain Hayes, wh will also be responsible for the property on board the ship, Mr. Ault may be authorized to proceed t the Baldwin Magnetic Observatory for the determination of the desired instrumental constants. * *

CRUISE II OF THE GALILEE, 1906.

W. J. PETERS IN COMMAND.

FROM GENERAL INSTRUCTIONS OF JANUARY 9, 1906, TO W. J. PETERS, WASHINGTON, D. C.

1. As soon as convenient, you will proceed to San Diego, California, via San Francisco, ar assume charge of the yacht *Galilee*, engaged in the magnetic survey of the North Pacific Ocean.

2. At San Francisco you will confer with Captain J. F. Pratt, at the suboffice of the Coast ar Geodetic Survey, regarding the duties assigned you. * * *

3. Respecting the alterations now being made on the *Galilee*, and their status, you will be a vised by Captain Pratt, whereupon you will relieve him of the supervision, and attend to su payments as he may advise you of. You have already been informed that the chief cause of tl compass deviations is located on the port side of the bridge and forward of the positions of t compasses, about in the direction of the port side of the old galley. It is quite possible that sor effect may also come from the iron material in the boat on the port side. You will make the desir

[1]See also paragraph 32 of J. F. Pratt's report, p. 133.

examination respecting this matter, and arrange to have this boat stowed elsewhere, if deemed necessary. * * *

FROM ROUTE INSTRUCTIONS OF JANUARY 20, 1906, TO W. J. PETERS, SAN DIEGO, CAL.

1. The general route to be covered in the forthcoming cruise is as follows: Leaving San Diego as early in February as circumstances will permit, sail on a direct course for Fanning Island, thence to Apia and Pago Pago, Samoan Islands. If, upon the completion of the work at the Samoan stations, it should be found feasible, proceed next to Suva, Fiji Islands, a cable station. From there, or from the Samoan Islands, as the case may be, take a course to Jaluit Island of the Marshall Group, where a good harbor will be found and supplies are obtainable, this being an important German trading-station. Proceed next by direct course to San Luis d'Apra, Guam, a cable station; leaving there, pass to the westward until the meridian of Yokohama (140° east) is reached, and thence proceed along that meridian to Yokohama or to the Gulf of Tokio, where a suitable place will be selected for the harbor swing. The aim should be to leave here not much later than July 1, in order to be sure of encountering as good weather conditions as possible on the return trip, going by direct course to Kiska Island of the Aleutian Chain, from there to Sitka, unless otherwise instructed, and then back to San Diego, endeavoring to reach this port in October 1906. [Owing to delayed departure from Yokohama, it was necessary on this cruise to omit the trip to Sitka and return instead by great-circle route to San Diego.]

2. It will be noticed that this cruise embraces a number of good supply stations, and, likewise, stations for controlling well your chronometers, as also affording facilities for excellent harbor swings and comparisons of instruments at three magnetic observatories (Apia, the German Magnetic Observatory, where one of the temporary observers of the Department, Mr. G. Heimbrod, is at present stationed; next, Tokio, and Sitka). * * *

FROM DIRECTIONS OF JANUARY 30, 1906, FOR SWINGS NO. 1 AT SAN DIEGO, TO W. J. PETERS.

1. Assure yourself that everything is in place on board ship as nearly as possible as at sea, being particularly careful about removal of all magnetic articles, as far as possible, in the vicinity of the bridge. Before beginning work, rehearse observers in operations assigned. Arrange to complete a swing, both helms, preferably morning or afternoon, or at least on same day. If conditions do not make 16 equidistant points feasible take 8. [8 equidistant headings were finally adopted.]

2. First swing, being an experimental one, will be confined to declination observations and comparisons of compasses on each heading, as follows:

A. One observer using Ritchie standard compass (R1B). Before beginning observations, mount the new cylindrical reflector in place of the deteriorated one in the azimuth circle, and take care not to disturb verticality of mounting. Obtain, if possible, on each heading 3 readings, using the reflector and prism, likewise 3 readings with alidade, alternating, preferably from one to the other, so as to determine effectively any possible difference between the two azimuth devices.

B. A second observer using the Negus compass and azimuth circle (D1), taking readings and following, as far as possible, the methods under *A*.

C. Mount on the gimbal stand an instrument for determining the compass deviations at this position, as required by theory. For this purpose the Kelvin dry compass and bowl, using the better one of the two compass cards, may be fastened to the top of the gimbal rings with the lubber-line as nearly as possible in the fore-and-aft line. * * * No azimuth device will be used, but comparisons be made as prescribed in *D*.

D. Comparisons between the Ritchie (R1B), the Negus (D1), and the compass on the gimbal stand to be made as follows, obtaining 3 readings in each instance:

When the ship's head is on the course, as shown by the Ritchie standard (R1B), the observer using this instrument will call out "On," whereupon the observers at the other compasses will read their respective cards. There will thus be afforded a check between the deviations obtained independently by the Negus and the Ritchie compasses. Owing to the less advantageous position of the Negus, it may happen that the solar observations will be cut out by an intervening mast more frequently than with the Ritchie; the attempt should be made, nevertheless, to obtain whatever conditions will permit.

E. The observations should be reduced and analysed, as soon as possible, and the values of *B* and *C* to the nearest minute and giving sign (whether plus or minus) for the 3 positions wired the Office. The detailed results will be mailed promptly.

F. Throughout above work no other magnetic instruments than those designated will be allowed on the bridge. (You were instructed by wire that the Kelvin compass is to be remounted; this applies only to the binnacle, it being not the intention to have the compass bowl mounted on the binnacle, except for occasional experiments at sea, as per directions supplied later.)

G. The *Galilee* will be steadied, of course, for a sufficiently long period on each heading to secure good results. All pertinent facts with regard to the swing and conditions under which made, list, roll, etc., will be fully recorded.

DIRECTIONS OF JANUARY 31, 1906, FOR SWINGS NO. 2 AT SAN DIEGO, TO W. J. PETERS.

1. Same preparations as called for in paragraph 1 of Directions for Swings No. 1 are to be made.

2. The special purpose of the second swings will be to determine the inclination and intensity deviations. Besides recorder, 3 persons will be requisite, one at Ritchie standard compass (R1B) to hold vessel on course, to call out to the observers when vessel is on course, and to record for one of the observers. One observer will make horizontal-intensity observations with sea deflector 1, and another will make inclination and intensity observations with sea dip-circle 35. The same remark, 2, *G*, Directions No. 1, applies here. The swing will be made on 8 equidistant points, with both helms.

3. Inclination and intensity observations with sea dip-circle 35.—First-helm swing; both loaded-dip observations (needle 4, weight 6), and regular-dip observations (needle 2), on each heading (scheme *A*). Other helm: deflection observations (scheme *B*). Schemes *A* and *B* are purposely made elaborate in order to ascertain cause of certain discrepancies which have revealed themselves in past swings. It will be far better to take all positions of circle and of needle on each heading every time rather than to multiply readings for any one position. However, as many readings as possible of both ends of needle should be made for each position. Care must be taken, before mounting the needle, that all dust has been removed from the dip circle, especially along the inner periphery of the vertical circle, near which the ends of the needle come, so that when lifting the needle its ends will not gather up fine dust-filaments. Likewise the blade of needle must be thoroughly clean and dry, so as not to introduce an additional balance error. As schemes *A* and *B* require rather frequent handling of needle, great care against injury to the pivots must be exercised, and the fingers be dry. The jewels must, of course, also be kept free of dust and moisture.

SCHEME A.—*First Helm: Loaded Dip and Regular Dip.*

No. of operation	Ship's head	Reading of mag. meridian on hor. cir.		Operation	Vertical circle	Face of needle	Vertical circle	Face of needle	Vertical circle	Face of needle	Vertical circle	Face of needle
		Cir. E.	Cir. W.									
1	N	....	....	Loaded dip..........	E	E	W	W	W	E	E	W
2	N	....	....	Regular dip, *A*[1] down....	E	E	W	W	W	E	E	W
3	NE	....	....	......Do..........	E	W	W	E	W	W	E	E
4	NE	....	....	Loaded dip..........	E	E	W	W	W	E	E	W
5	E	....	....	......Do..........	E	W	W	E	W	W	E	E
6	E	....	....	Regular dip, *A* down.....	E	E	W	W	W	E	E	W
7	SE	....	....	......Do..........	E	W	W	E	W	W	E	E
8	SE	....	....	Loaded dip..........	E	E	W	W	W	E	E	W
9	S	....	....	......Do..........	E	W	W	E	W	W	E	E
10	S	....	....	Regular dip, *A* down.....	E	E	W	W	W	E	E	W
11	SW	....	....	......Do..........	E	W	W	E	W	W	E	E
12	SW	....	....	Loaded dip..........	E	E	W	W	W	E	E	W
13	W	....	....	......Do..........	E	W	W	E	W	W	E	E
14	W	....	....	Regular dip, *A* down.....	E	E	W	W	W	E	E	W
15	NW	....	....	......Do..........	E	W	W	E	W	W	E	E
16	NW	....	....	Loaded dip..........	E	E	W	W	W	E	E	W

[1] Polarity of needle 2 to be same throughout swing; however, needle should be well magnetised before swing, and so that the *A* end will be *down*.

SCHEME B.—*Other Helm: Deflections with Sea Dip-Circle.*[1]

[1]Needle 4 will be placed inside aluminum case so as to bring letters *A*, *B* *toward* observer for *short* distance, and away *from* observer for *long* distance, and is not to be touched thereafter for the entire swing. Face of needle 3, throughout swing will be *toward* observer for short distance, and *away from* observer for *long* distance.

SCHEME C.—*First Helm: Deflections with Sea Deflector, using Magnet 45.*

No. of operation	Ship's head	Prism	N. end of magnet	Prism	N. end of magnet	Prism	N. end of magnet	Prism	N. end of magnet	Letters on magnet
1	N	S	E	N	W	N	E	S	W	Up
2	NE	S	W	N	E	N	W	S	E	Up
3	E	S	E	N	W	[illegible]	E	S	W	Up
4	SE	S	W	N	E	N	W	S	E	Up
5	S	S	E	N	W	N	E	S	W	Down
6	SW	S	W	N	E	N	W	S	E	Down
7	W	S	E	N	W	N	E	S	W	Down
8	NW	S	W	N	E	N	W	S	E	Down

SCHEME D.—*Other Helm: Deflections with Sea Deflector, again using Magnet 45.*

No. of operation	Ship's head	Prism	N. end of magnet	Prism	N. end of magnet	Prism	N. end of magnet	Prism	N. end of magnet	Letters on magnet
1	N	N	E	S	W	S	E	N	W	Down
2	NW	N	W	S	E	S	W	N	E	Up
3	W	N	[illegible]	S	W	S	E	N	W	Up
4	SW	N	W	S	E	S	W	N	E	Up
5	S	N	E	S	W	S	E	N	W	Up
6	SE	N	W	S	E	S	W	N	E	Down
7	E	N	E	S	W	S	E	N	W	Down
8	NE	N	W	S	E	S	W	N	E	Down

4. Horizontal-intensity observations with sea deflector 1 (D1).—Schemes *C* and *D* will be followed. Care is to be taken in the temperature readings, end of block containing deflecting magnet being protected against air currents. Magnet NL will not be used for these swings, solely magnet 45. (Directions regarding use of magnet NL will be supplied later.)

5. Should it be found feasible, there will be no objection against securing declination determinations during the swing by the person at the Ritchie standard compass (R1B); this matter must be left to the commander's judgment. The method outlined in schemes *C* and *D* will again afford data for determining the deviations of the Negus compass (D1) without making azimuth observations.

6. The Kelvin compass will of course not be mounted on its binnacle throughout these swings; this compass is to be used only for certain experimental work at sea.

DIRECTIONS OF FEBRUARY 8, 1906, FOR SWINGS NO. 3 AT SAN DIEGO, TO W. J. PETERS.

Same as for swings No. 2, except for following modifications:

1. First helm: Deflections with sea dip-circle, beginning with long distance, instead of short distance; face of needle 3 to be towards observer for long distance and away from observer for short distance.

2. Other helm: Loaded dip and regular dip (needle No. 2 again, but this time *B* end down) with sea dip-circle.

3. First helm: Deflections with sea deflector, using this time magnet NL with letters up throughout.

4. Other helm: Deflections with sea deflector, again using magnet NL, but now with letters down throughout.

5. Declinations to be obtained by the observer at the Ritchie standard compass (R1B), taking 3 readings, on each heading, for both helms.

INSTRUCTIONS OF FEBRUARY 9, 1906, FOR SEA OBSERVATIONS, TO W. J. PETERS.

1. When all instructions regarding the observations and computations for the work at San Diego have been completed, and the original records have been forwarded to the Office, please wire when you are ready to go to sea, and await telegraphic advice. You have already received instructions regarding route (Jan. 20, 1906).

2. *Disturbing Causes.*—You have already been cautioned as to the need of excluding, so far as lies within your power, any extraneous, artificial disturbing influences likely to affect the work assigned. You will accordingly see to the proper disposition of articles on and in the vicinity of the bridge, removal of magnetic articles from the observer's person, etc. Each observer will state on his record sheet of observations whether he had removed all magnetic substances. Statements regarding the various conditions under which observations and swings are made can not be too full. Roll of vessel, weather conditions, condition of ship, manner of swinging, and all other pertinent facts should receive proper attention in the notes.

3. *Geographic position of ship during observations.*—The need of giving this matter your special attention has already been fully explained. The observations and computations should be arranged, as far as possible, to afford opportunity for independent checks.

4. *Swings at sea.*—A complete swing at sea must be obtained with both helms, covering 8 points as well as conditions permit, as soon as possible after leaving San Diego Harbor. Thereafter the attempt will be made to obtain a swing every third day, and, in no instance, should more than a week be allowed to elapse between two swings, if conditions of sea and weather do not prevent. Whenever possible the three magnetic elements, declination, inclination, and intensity, are to be secured on the same swing. Cloudiness, however, will at times prevent this ideal combination and the work will have to be arranged accordingly. Cloudiness will not be an excuse, however, for not swinging at least for inclination and intensity; the ship deviations for both of these elements, on account of their greater comparative magnitude and greater susceptibility to change than the declination deviations at the position of the Ritchie standard (R1B), require more frequent control.

The general program of magnetic work for a swing will be as follows:

a. Declination observations with the Ritchie standard compass (R1B), securing 3 readings so far as possible on each heading of both port-helm and starboard-helm swing, increasing the number, if necessary, in accordance with the conditions encountered.

b. Horizontal-intensity observations with sea deflector (D1).—Magnet 45 is to be used throughout for both helms, having letters "up" for first swing, and letters "down" for return swing. Invariably on each heading the four positions or readings will be taken.

c. Inclination and total intensity with sea dip-circle (D. C. 35).—First helm: Loaded dip (needle 4, weight 6), invariably on each heading for the two positions circle east face of needle east and circle west face of needle west, needle not to be turned around (inverted) throughout the swing, and at least 2 independent readings to be secured for each end of the needle in each of the two positions prescribed. Other helm: Deflections, using both distances.[1] Thus, *e. g.*, short

[1] Both deflection distances may require too much work. If so, it will suffice to take but one distance, using for one station the short one, for the next station the long one, thus alternating the two distances. When a single distance is used, then 2 readings should be taken on each end of the needle. Whenever but one end of a needle can be used, whether in dip or intensity work, then readings on the visible end will be multiplied.

b. To afford some experience with the Kelvin compass, the latter should be mounted when no horizontal-intensity observations are being made with the sea deflector, and declinations should be observed with it. In order to determine the ship deviations for the Kelvin compass, as also those for the Negus compass when used for declination work, several comparative readings of the lubber-lines with the Ritchie standard (R1B) should be made before and after a series of declination observations on any particular course.

c. When the Kelvin compass is mounted, attempt should be made to determine the period of vibration of the particular card used, and a record be kept of the various places at which these experimental observations are made. (The purpose is to ascertain whether a vibration method could be as advantageously employed as the present deflection method. The Kelvin compass will of course not be kept on the bridge when likely to affect the other work going on at the time.

d. Occasional horizontal-intensity observations with the sea-deflector attachment mounted on the Ritchie standard compass (R1B).

8. *Meteorological observations.*—These observations will be made in accordance with the directions supplied by the United States Weather Bureau. Whatever additional marine observations may be possible must be left to the commander's discretion.

9. *Reduction of observations.*—The endeavor should be, in general, to keep computations up to date, though they should not be allowed to interfere with the time for observations. No attempt is to be made to determine and apply precise corrections, the scheme of work in fact being now arranged so as to avoid the necessity of applying such corrections, as, *e. g.*, position corrections. All corrections to be applied, whether for position or for reduction to standard, now solely affect the A coefficient of any element involved, and will not affect the harmonic coefficients B, C, D, and E. The analysis will invariably be made without A, and the final determination of A left to the Office. It will be best accordingly, at present, not to apply any corrections of the nature mentioned.

10. *Records of observations.*—The original records are to be promptly forwarded, by registered mail, at each port of call, and not be allowed to accumulate any more than necessary. Even if the computations are not complete, it will be preferable to transmit the records. Abstracts should be made of the essential quantities to guard against loss of work in transmission to the Office, and for use aboard ship. There will thus be afforded the Office opportunity to determine whether any revisions in directions are necessary.

11. *Shore observations.*—Descriptions of stations and directions are embodied in a separate communication.

FROM INSTRUCTIONS OF FEBRUARY 10, 1906, REGARDING LAND MAGNETIC OBSERVATIONS, TO W. J. PETERS.

1. The land observations will in general be made principally with the Coast and Geodetic Survey magnetometer 36, sea dip-circle 35, land dip-circle 178, and sea deflector 1 mounted on Negus compass, using magnets 45 and NL. The observations should be arranged so as to vary the corrections for diurnal variation and to reduce the effect from possible magnetic storms as much as possible by distributing the observations over two or more days (if there be opportunity), rather than increasing the number on one day. They are also to be arranged so as to secure as good comparisons as possible of the instruments. The results are to be completely reduced before the vessel leaves, in order to afford opportunity for repetition, or to ascertain the cause of any observed discrepancy in the constants or results. The importance of the land work in the determination of the final corrections and constants for the ship work must not be overlooked.

2. When the Negus compass is mounted on land, declination observations should be made, preferably both by direct reading of azimuth mark and by sun-azimuths, so as to test the azimuth devices used on board ship. Adjustments should not be disturbed, however, unless there be good reasons; in the latter case, full record must be made. The same statement applies to the testing of the Ritchie standard compass and azimuth arrangements, and when determining the intensity constant for the azimuth circle used in connection with any deflector observations that may have been made. So likewise, if the Kelvin compass has been used for occasionally getting vibrations and declinations, certain shore observations will be desirable. These matters must be largely left to the commander's discretion, as they depend upon the precise circumstances involved. Shore observations and intercomparisons or tests of instruments may at times be facilitated by establishing a

second station in the vicinity of the primary one, say not less than 30 feet away, and placed in the direction of one of the azimuth marks, azimuth of which has been or can readily be determined by angular measurements. It will thus be possible for two persons to observe at the same time; by exchanging stations, data will be obtained for reducing the respective observations to the same station.

3. The principal tests of the instruments will be made at the German Meteorological and Magnetic Observatory, Apia, Samoa, at the Tokio Central Meteorological and Magnetic Observatory, also possibly at Sitka Magnetic Observatory. By conference with the respective directors, you will be able to decide mutually on the precise manner in which the desired tests and intercomparisons are to be made. At these, as also at other stations, opportunity will be afforded for the rating of chronometers, and for the requisite standardizing of any of your meteorological instruments.

4. There are inclosed 23 sheets giving information regarding previous stations and observations at points along a portion of the route of the coming cruise. No definite instructions can be given as to which of these stations it will be feasible to occupy, and this matter will have to be left to the commander's judgment. * * *

CRUISE III OF THE GALILEE, 1906–1908.

W. J. PETERS IN COMMAND.

FROM ROUTE INSTRUCTIONS OF NOVEMBER 22, 1906, TO W. J. PETERS, WASHINGTON, D. C.

1. As soon as possible after December 1 next, you will please carry out the following cruise:

San Diego, California, by direct course to Nukuhiva (Marquesas Islands), thence to Tahiti, next to Apia, from which port shape a course for Yap, intermediate between that of second cruise and Solomon Islands. From Yap, proceed to Shanghai by direct course, thence to Hongkong.

[From Shanghai the *Galilee* proceeded to Sitka. Head-winds prevented making Midway without considerable loss of time. Near the one hundred and eightieth meridian the course was shaped for Sitka on account of the approaching end of the season. Declinations were possible only on 8 days between Shanghai and Sitka, owing to continued cloudy weather. The route from Sitka, according to supplementary instructions of August 3, 1907, prepared at Sitka, is sufficiently indicated by the ports of call—Honolulu, Jaluit, Christchurch, Callao, San Francisco. See also abstracts of logs.]

DIRECTIONS OF NOVEMBER 30, 1906, FOR SWING OBSERVATIONS, TO W. J. PETERS, SAN DIEGO.

1. When everything is finally in place on board as at sea, swing ship on 8 equidistant points (both helms) shortly before leaving San Diego, observing as follows:

A. Declination observations with the new Ritchie compass 29499 (R3C) and new azimuth circle 481, using both prism and alidade, and observing preferably on the Sun.

B. Horizontal intensity observations with sea deflector 1, using magnet 45, short distance, letters up on first helm, and same magnet, letters down, on other helm. (From these observations are secured likewise, as before, the declination deviations for the Negus compass.)

C. Inclination and total intensity with sea dip-circle 35. On first helm throughout, loaded-dip observations, complete set on each point as heretofore; on the other helm, deflection observations, long distance, face of suspended needle "direct" throughout, and set complete on each point same as hitherto. [Supplemented December 10, 1906, as follows: In swings, alternate dip circles 35 and 169, *i. e.*, if for one swing No. 35 has been used then for next swing use No. 169. In both cases, however, make deflections only with long distance.]

D. Should there be opportunity during the swing, it would be very desirable for someone to try observing the time of vibration of the new Kelvin card No. 8127 on as many headings as possible. (It is desired on this cruise to ascertain definitely whether vibrations are feasible.)

2. All other swings, whether in port or at sea, will be precisely the same as the San Diego ones, excepting as pertains to *C*, first part, viz, if loaded-dip observations were secured on first helm, then for next helm make, instead, regular-dip observations with the best dip needle on hand, keeping same polarity throughout. Furthermore, helms should be alternated; thus, if on port-helm swing the observations consisted of loaded dip (or regular dip), and on starboard-helm swing deflections were made, then next time make the latter observations on port-helm swing, and the former on starboard-helm swing, etc.

3. The liability to changes in ship deviations dependent upon length of time on course pursued or on direction of vessel while in harbor, or upon conditions of sea and weather, etc., should be borne in mind. Hence swings should be secured at sea as soon as possible after leaving, or before entering a harbor, and the harbor swing be made immediately upon arrival.

4. The San Diego observations should be mailed before departure.

5. The sea swings will be obtained as often as conditions of sea, weather, and time permit.

6. Satisfactory swings in one port at least (if possible two ports) in the Southern Magnetic Hemisphere are required.

DIRECTIONS OF NOVEMBER 30, 1906, FOR COURSE OBSERVATIONS, TO W. J. PETERS, SAN DIEGO.

1. The course observations will in general be made as on previous cruise, endeavoring, if possible, to obtain the three magnetic elements (declination, dip, and intensity) for the same geographical position.

A. Declinations will be obtained as frequently as possible with both Ritchie compass and Negus compass, laying principal stress, however, upon the former instrument. Declinations with the Kelvin compass are optional; it will not be amiss, however, to experiment further with the various azimuth devices employed with this instrument. As indicated under "Swing directions" (1D), it is especially desired to try this compass for vibration observations. (If such experiments have been made, corresponding shore observations are required for determination of intensity constant.)

B. The sea-deflector work, simultaneous with the sea-dip-circle observations, will consist of horizontal-intensity observations, using both magnets 45 and NL (only short distance in each case), letters up and down, same as hitherto. (When observations are possible with only one magnet, use 45).

C. The sea-dip-circle work will consist, as heretofore, of total-intensity observations made between the regular-dip observations. Only one deflecting distance will be used throughout, observing, however, each time with both face "direct" and "reversed" of suspended needle. For the region in which the dip is above 40°, alternate long and short distance will be used, whereas for region below 40° only long distance. [Supplemented on Dec. 10, 1906, as follows: Alternate dip circles 35 and 169, *i. e.*, if 35 was used at one place of observation, then use No. 169 the next time. In case of No. 169, however, observe deflections with both distances, each time whenever possible. For symmetry of the work, it would therefore be desirable to make a double set of deflections with No. 35 for the single distance used.]

D. Miscellaneous observations, astronomical, meteorological, etc., to be made as opportunity affords.

2. While it will be best that each observer have his own particular instrument throughout the cruise, it is desired, however, that each one familiarize himself sufficiently with the instruments and work of the others, so that, if suddenly called upon, he may be able to perform another's duties. Observers must bear in mind that for successful office reductions notes can not be too full.

DIRECTIONS OF NOVEMBER 30, 1906, FOR LAND OBSERVATIONS, TO W. J. PETERS, SAN DIEGO.

1. Besides the observations with magnetometer and land dip-circle, dips and total-intensity observations are required, in each instance, with the sea dip-circle. Deflections, both distances, will be made at San Diego, Tahiti, Zikawei, Honolulu, Dutch Harbor, Sitka, and again at San Diego; at the other ports only long distance will be used. [Supplemented on December 10, 1906, as follows: On land, both sea dip-circles 35 and 169 will be used. Where in the case of No. 35 only one deflection distance is prescribed, invariably make a double set. With No. 169, deflections will always be made with both distances until otherwise instructed. With No. 35 both deflection distances are to be used at San Diego, Tahiti, Zikawei, Honolulu, Dutch Harbor, Sitka, and San Diego, whereas with magnetometer 1 both deflection distances are to be used at Tokio, Honolulu, Dutch Harbor, Sitka, and San Diego.]

2. Make necessary shore observations (lubber-line on 8 points) for testing compasses and azimuth devices used in declination work. (When theodolite-azimuth method is used, as on previous cruise, all time data required for likewise computing azimuths should be given without fail.)

3. Make sea-deflector observations for determining intensity constants (lubber-line on 8 points).

4. Especial care should be taken with the shore observations, varying the conditions as far as feasible, making them in sufficient number to insure good determinations, and distributing them so as to eliminate, as far as possible, diurnal-variation corrections. When it is necessary to occupy two stations, some tests should be made to insure that there is no appreciable difference in the values of the magnetic elements at the two stations. Full descriptions of land stations must be given. Even if an old station is reoccupied some statement should be made as to surroundings, etc. Notes as to geological formation are specially desired. Observers should remember that the office computer has no knowledge as to the conditions under which observations were made. When intercomparisons are made with other instruments, full record should be made as to methods used and of instruments compared with. In intercomparisons with observatory instruments, stations should likewise be exchanged, unless the local observer deems the exchange unnecessary.

5. Prime attention should be paid to the official photographic views of stations, instruments, observing party, foreign observatories, etc., for use in illustrations for the published reports.

6. When necessary to observe dip or intensity out of meridian, make the observations, whenever possible, in magnetic azimuth: $a = \pm 45°$. The same remark applies to sea observations.

FROM DIRECTIONS OF AUGUST 5, 1907, TO W. J. PETERS, SITKA, ALASKA.

In the future ocean and land magnetic work, the following decisions are to be observed:

a. The determination of constants for sea dip-circles 169 and 189 should also include 2 sets of regular-dip observations with the suspended needle used in deflections, but not reversing polarity.

b. The vibration observations with the Kelvin card may be discontinued. [These observations had been extended over a period long enough to show that the vibration method of obtaining intensity, with the present appliance, would not be satisfactory.]

c. In order to facilitate swings, the deflector observations may be reduced to 2 sets, instead of 4, as hitherto, on each heading. On the first-helm swing, one deflector magnet will be used throughout and in the other-helm swing the second magnet will be used. Should experience show that this reduction in the number of sets is not advantageous, you are at liberty to increase the number. Furthermore, if there are cases in which it is more advantageous to make a swing first for declination deviations alone, and thereafter for the other elements, you are authorized to do so.

d. The sea-deflector observations on course will require special attention. Both lubber-lines will invariably be read. The same method as employed at Sitka will be used. In order to vary the conditions somewhat, make sets as follows:

(1) "A" of azimuth-circle bows towards observer.
(2) "B" " " " "
(3) "A" " " " "
(4) "B" " " " "

Similarly 4 sets with the other magnets.

e. Whenever there is choice as to sea dip-circle, give preference to 189.

f. At Honolulu, obtain the intensity constants for the two sea dip-circles for as great a range of temperature as may be possible. For sea deflector 2 (D2), after the observations have been made on 8 points for both magnets, then make them on the intermediate 8 points at a temperature differing as widely from the first set as conditions permit.

FROM INSTRUCTIONS OF MAY 2, 1908, TO W. J. PETERS, SAN FRANCISCO.

1. Upon arrival at San Francisco, you will carry out all observations in connection with the swings of vessel which may be necessary for the satisfactory and complete reduction of the ship observations. Before making any alterations of vessel, please wire your opinion as to the satisfactory outcome of observations. It will be highly desirable to make complete swings on at least two days for all elements. You will be informed later whether to proceed with alterations.

2. The principal land-station for the testing of instruments will be Goat Island, as in 1905. Observations at this point should extend over at least 2 days to secure a satisfactory determination of secular change. San Rafael is likewise to be occupied on 2 days. * * *

EXTRACTS FROM FIELD REPORTS AND ABSTRACTS OF LOGS OF THE GALILEE.

The following extracts from field reports made to the Director at the end of each cruise by the respective commanders of vessel will serve not only to supplement what has already been given, more or less briefly, on pages 8 to 14, but will also be found to contain most interesting and valuable information as to the conditions encountered, the work done, and the manner in which a cruise was accomplished.

EXTRACTS FROM FIELD REPORTS.

J. F. Pratt: Alterations of the Galilee, and her First Cruise.

1. Beginning at San Diego, Cal., the scientific personnel of the ocean party in my charge was as follows: J. F. Pratt, in command; Dr. Hobart Egbert, surgeon and observer; J. P. Ault, observer, and P. C. Whitney, observer and watch officer. [The Director, Dr. L. A. Bauer, accompanied the vessel on the experimental portion of the cruise from San Francisco to San Diego, during which he supervised the arrangements for the scientific work, completed the training of the observers in the magnetic work, tried out and devised the methods of observation, and decided on the final program of work. Under his direction, also, Messers. Egbert and Ault made the required observations in the vicinity of San Francisco for determining the magnetic elements at the locality selected for swinging ship, and for the determination of magnetic constants of the various instruments and of the vessel.]

2. My entire connection with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington was as follows: Between April 16 and June 3, 1905, my services were of an advisory nature, relating to weather conditions for the forthcoming cruise, the questions of stability, construction of ordinarily composition-fastened vessels, with special reference to the amount of iron in their hulls, suitable rig, reconstruction of quarters, and the recommendation of the use of a specially constructed flying bridge. Between June 4 and December 17, 1905, at the request of the President of the Carnegie Institution of Washington and by permission of the Honorable the Secretary of the Department of Commerce and Labor, I was on leave of absence, without pay, from the Coast and Geodetic Survey, and on annual leave granted by the Department of Commerce and Labor from December 18 to 22, 1905, being under pay from the Carnegie Institution of Washington from June 4 to December 22, 1905. Between December 23, 1905, and February 8, 1906, my services were gratuitous; they consisted in conferring with the owners of the vessel regarding the changes mentioned in paragraph 32, in acquainting my successor (W. J. Peters) with the condition and necessities of the vessel, etc. Between February 9 and 28, 1906, I was again on leave of absence, without pay, from the Coast and Geodetic Survey, and under pay from the Carnegie Institution of Washington.

3. On June 6, 1905, just after my arrival in San Francisco from Seattle, Washington, a conference was held with the owners of the *Galilee*, and an understanding arrived at as to the contemplated changes and the manner in detail of carrying them out.

4. The *Galilee* is a brigantine, her custom-house register being 354 gross and 328 net tons; length 132.5 feet, breadth 33.5 feet, depth 12.7 feet; crew 8; built in 1891 at Benicia, California. Her general dimensions are approximately as follows:

	Feet		Feet
Length over all, extreme	189	Draft, extreme as ballasted for cruise	10
Length over all, of hull	140	Freeboard bow	13
Length on water line as ballasted for cruise	128	Freeboard stern	10
Overhang, forward	3.5	Least freeboard, including bulwark as ballasted	8.5
Overhang, aft	8.5	Height of fore truck above water line	120
Breadth, extreme	32.5	Height of main truck above water line	121

The sails used during the present cruise consisted of the following: foresail, lower foretopsail, upper foretopsail, fore topgallantsail, fore royal, jib, flying jib, outer jib, middle mainstaysail, leg-of-mutton mainsail, ringtail maintopsail, and fore balloon-studding-sails; the combined area of the foregoing being approximately 10,952 square feet.

5. This vessel has the reputation of being one out of three of the smartest small sailing-vessels on the Pacific Coast of the United States, her greatest record being 308 miles in 24 hours with full cargo. It will be observed that the length of her masts is practically her water-line length. Owing to the great proportionate beam, 1 to about 4, and large, very flat floors, she is unusually stiff; her lines are not particularly easy, her speed and capacity to carry on sail being greatly due to the large dead rise, 1 to about 3, combined with great stability and comparatively light draft. The hull and spars are constructed of Douglas fir. The *Galilee* is a composition-fastened vessel, *i.e.*, the outside planks are fastened with composition (a grade of brass) spikes. The frames are "sawed out," are

FIG. 4.—Section of the Galilee, showing Iron Fastenings.

double, being about 12 inches by 12 inches and spaced, from center to center, 28 inches; the deck beams are about 10 inches by 12 inches and spaced about 4 feet. The broken lines in Figure 4 show the distribution of iron fastenings in frames, hanging knees, and deck beams; the bosom and lodging knees together contain about the same quantity of round iron fastenings as the hanging knees. The double broken lines include round iron fastenings, while the single ones indicate iron spikes. The round iron fastenings vary in size from $\frac{3}{4}$-inch in the bulwark caps to $1\frac{1}{2}$-inches in the keelsons and sister keelsons, those in the thick strakes of the ceiling and hanging knees being about 1 inch; the spikes are $\frac{7}{8}$-inch and $\frac{5}{8}$-inch square in cross-section, varying in length from 7 to 10 inches.

6. The *Galilee's* standing rigging was composed of the customary galvanized-iron wire rope, which had to be removed and hemp substituted; as hemp standing rigging has become obsolete, except for vessels used in Arctic regions, sufficient hemp of the various sizes required could not be

obtained on the Pacific Coast. In consequence a blue-print plan of the original rigging was furnished, at the instance of the Director of the Department, to a firm in Philadelphia, Pennsylvania, which supplied the requisite material, shipping it as fast freight to San Francisco. During the period of transit of the hemp rigging, a competitive award was made with a firm of riggers to strip the vessel of the old wire, and to fit and set the new gang of hemp, all of which was accomplished, inspected, and accepted by July 17, 1905.

7. The officers' quarters of the ship consisted of a very small cabin and 3 adjacent staterooms, which accommodated the sailing-master and the two mates only. As it was necessary to have additional room for the scientific personnel, the necessary quarters were provided by designing and constructing an additional house forward of and against the old one. Although separated from the old cabin by a solid bulkhead, the new deck-house appeared as a continuation of the original house, it being of the same width and length. This addition was approximately 20 by 22 feet outside measure, and contained a combined working, dining, and living room, with 3 staterooms opening off on the starboard side, and a transom and small pantry on the port. It was originally intended that the scientific party should consist of commander of vessel and 2 observers; hence the 3 single staterooms were deemed sufficient. However, a few days before sailing, it was decided that an additional observer was necessary, but, as there was insufficient time to construct an additional stateroom, he was obliged to sleep on the transom throughout the cruise. The furnishings, selected and procured for these quarters, consisted of linoleum for the deck, a small floor rug for each of the staterooms, 2 pairs of blankets for each person, crockery, glass, plated ware, and cooking utensils sufficient for the number of persons, and table and bed linen in sufficient quantities to last with care for periods of 6 or 8 weeks.

8. The fresh-water tanks had been carried on the main deck in front of and against the after house; before commencing the construction of the new house, they were moved to the forward portion of the hold. In addition to the old ones, the owners added more tanks, stowing them in the same locality, so as to nearly double the fresh-water storage capacity of the vessel.

9. The after portion of the forward deck-house contained a donkey engine for hoisting, and a boiler; these with all their fittings and fastenings were taken out and put ashore, the space occupied by them being fitted up as a forecastle. As the galley, being 6 feet by 9.5 feet and containing a cooking range with a small cook's bench, was too small for 2 men to work in at a time, the original forecastle was fitted for and used as a store room and a steward's working pantry.

10. The elevated flying bridge, alluded to in paragraph 2, was constructed entirely of wood, with brass and copper fastenings, the deck of the bridge being 6 feet 1 inch by 31 feet 8 inches, and 12 feet 1 inch above the main deck. It was so designed that the instruments mounted on their respective stands and binnacles would be between 15 and 16 feet above the main deck, and at least 12 feet above the horizon of the windward waterway when the vessel was heeling 10°. The bridge was supported by 3 sets of trestles, proportioned so that their tops were of the same width as the bridge, and spread so that their bases were about 10 feet 8 inches; 2 sets of these supports were bolted with brass to the main deck, and the third of the same proportion was bolted to the top of the forward house. The deck sills (corresponding to mud sills) were about 8 inches by 8 inches; the supports were 6 inches by 6 inches; and were carefully braced in both fore-and-aft and athwartships directions. The sills of the bridge proper were 4 inches by 8 inches, and the hand-rails were 3 feet high; the bridge was reached by a companion ladder leading up through a trap-door in its after end, and also by one leading from the forward end down to the roof of the forward house. (Pl. 1, Fig. 3.)

11. The final completion of the flying bridge was postponed until the arrival of the instruments from Washington; on their receipt it was soon completed, and the instruments were spaced and arranged in accordance with the Director's instructions.

12. The *Galilee's* crew, according to the charter-party, consisted of 2 mates, 6 seamen, a ship's cook, and a steward for the separate mess of the scientific party. These 10 men, together with the sailing-master, were furnished by the vessel owners, subject to the approval of the commander of the vessel.

13. By August 1, 1905, the stores for the cruise were stowed aboard, and the instruments on the bridge were carefully adjusted and alined. On August 2, 3, and 4 the vessel was swung, under the Director's instructions and supervision, in the channelway between Goat Island and the Berkeley water-front, San Francisco Bay. The swings were made with the *Galilee* in tow, astern of a tug,

first on an even keel with both helms, and then with both helms heeled to port and starboard, successively, as much as could be accomplished with the weight of two heavy boom-sticks hoisted out of water, first on one side and then on the other. The vessel was so stiff that the weight, which was all that could be handled with the available purchase, listed very much less than anticipated.

14. On August 5, 1905, at 2 p. m., the *Galilee* was towed out of San Francisco Harbor, and just outside the heads we set sail for San Diego, California. By standing offshore about 200 miles, it was hoped that we would be beyond the foggy and overcast influence of the northwest trades on the coast, but such was not the case. We then headed inshore toward Point Conception for a possible change for the better in the vicinity of Santa Barbara Island, but with ill success. It was not until the afternoon of the 10th, when northeast of San Clemente Island, that the Sun shone, and the ship was swung under sail for the first time. At $4^h 30^m$ p. m. August 11, we anchored at the entrance of San Diego Bay, 6 days from San Francisco, and signaled for a tug to tow us in, but could not get one until the afternoon of the following day; so we did not come alongside the dock in San Diego Harbor until $4^h 30^m$ p. m. August 12, 1905. During this experimental cruise from August 6 to 12 the new hemp rigging had to be temporarily set up at sea, and at San Diego it all had to be systematically and carefully set up, and some of it had to be turned in and reserved.

15. Between August 14 and 21, 1905, magnetic observations were made at 4 shore stations at San Diego and vicinity in order to find 2 stations having practically the same declination and so situated that the ship could be swung between them. On August 22 and 23 the ship was swung at San Diego, between the two selected shore magnetic stations, one on each side of the channel-way.

16. Based on shore experiments at San Diego, the distance was increased between the standard compass 29971 and the deflecting compass 31974, and the Kelvin compass was removed entirely, the sea dip-circle remaining where it was before. As seen from Figure 2 and pages 26–28, the 3 instruments used on the remainder of the cruise were 10 feet 10 inches apart, the former distances being thus increased by 2.5 feet, which was all that the arrangement of the present bridge would allow. After the instruments had been carefully adjusted and alined, so that their lubber-lines were in the same fore-and-aft plane, the ship was swung on August 24, 1905, at San Diego in the same place and manner as on the 2 previous days, for determination of the constants for the new spacing of the instruments.

17. Trouble had been experienced with the ship's small liquid steering compass when swinging under sail; this was on account of the small spacing of the subdivisions of the card, so that the helmsman could not satisfactorily steady the vessel for the desired heading on which magnetic observations were to be made. Accordingly, it was necessary to replace the former steering compass by the available Kelvin dry compass, with its 12-inch card and large graduations.

18. On August 25, 1905, the day after completion of all swings, the union crew shipped in San Francisco struck; being very troublesome, they were paid off and discharged on the following day. The next day, the 27th, a new, indifferent crew was hurriedly brought aboard, and an effort was made to get away. The tug was alongside, lines singled up, orders given to cast off, when the crew all walked ashore and declared that they were not willing to go. Apparently the available seamen in San Diego were exhausted, and the owners' agent telegraphed to San Pedro for men, but the reply came back that there were none available there. Learning that there were about 6 men working in a brickyard out near La Jolla, who a few weeks previously had left an English ship, I immediately sent Captain Hayes, the master of the *Galilee*, there, and he succeeded in persuading them to ship. On the following afternoon, September 1, 1905, the *Galilee* was towed out of San Diego Harbor, and at $3^h 35^m$ p. m. we squared away for Honolulu, taking our departure from Coronado Hotel and Point Loma Lighthouse. During the first 2 days out the wind was not fair and we sagged off to the southwest, but after that the course was practically a great circle to Honolulu, which was reached on the morning of September 16, making a distance of 2,331 nautical miles in less than 15 days.

19. During the first portion of the voyage the weather was unfavorable for magnetic work, very showery and overcast, and two of the observers were sick. Conditions were such that the ship could be swung on but 2 days, and observations could be made on course on 7 days. During this passage most of the rigging had to be set up twice, and many of the lighter and longer stays three times.

20. While at Honolulu all the instruments were taken to the Coast and Geodetic Survey magnetic observatory at Sisal, and complete observations were made there for constants. This work

occupied the observers from September 18 to 21, 1905. The scientific party was engaged in office work, preparing the records and computations for transmittal to Washington, from the 22d to the 27th. During all the time that the vessel was at Honolulu the ship force was constantly engaged in overhauling, turning in, and setting up the new standing rigging. On September 28, 1905, the vessel was towed out of Honolulu Harbor to and abreast the Honolulu Magnetic Observatory at Sisal, where it was swung with both helms, which took until nightfall, when we proceeded to sea.

21. The cable company at Honolulu reported unusually stormy weather at Midway Island, and a schooner from the westward reported that there was extremely heavy weather beyond Kauai. Owing to these reports, and the knowledge that all along the windward side of the chain extending from Honolulu to Midway heavy weather generally prevails, it was deemed best to go around the Hawaiian Islands, via the pass between Maui and Hawaii, and then go northwest from the south extremity of Hawaii Island, crossing the heavy-weather belt once or twice rather than to parallel it; while in this belt, the sea would be too heavy to make magnetic observations. The course from Honolulu was set accordingly, but the light and baffling airs, coupled with unexpected calms and the strong westerly current in that region, caused our little sailing-vessel to fall off so that she could not make the schooner route from Honolulu to Hilo, via Aleuinhana Channel. When about 300 miles to the southward of the southern extremity of the island of Hawaii, the conditions being favorable, I decided to continue on to Fanning Island, make a base station there, and cross the chain to the westward of Honolulu later, as the winds and currents would now compel us to do under any circumstances whatever. Fanning Island was reached on the afternoon of October 10, the vessel being out from Honolulu 12 days, and sailing and drifting 1,207 miles. During this passage the weather conditions were such that the ship was swung on 1 day; on 8 days observations were made on course; on 2 days it was too stormy to observe; on 2 days, during which it rained a great deal, course observations were made between showers; on 3 days the wind was too light to swing ship, and on 7 days the Sun only shone at intervals between showers and clouds.

22. The "Pacific Cable Board," a governmental cable, maintained by some of the Pacific British colonies and the home government, has a cable station on Fanning Island and maintains a mooring-buoy at the old whalers' anchorage, in front of the station. The shore magnetic station, where all the magnetic observations and comparisons were made, is directly back of the cable station, between it and the Central Lagoon, and not far from the boat-shed on the lagoon. The *Galilee* was swung both to port and to starboard from the mooring-buoy, utilizing the prevailing wind-and-ocean current, and using long shifting and veering lines. The stop at Fanning Island covered 4 days, October 10 to 14. Mr. Smith, the local manager of the cable station, together with his corps of assistants, showed the party every courtesy possible. The landing at the cable station is on the outside of the ring-shaped island and in the surf.

23. Fanning Island is about 200 miles from both the geographic and the magnetic equators. Judging from weather conditions experienced by Captain Hayes on several occasions between Fanning Island and the Pacific coast, it appeared that, under average conditions, we would make the passage back to California in ample time. Accordingly it was decided to cross the magnetic equator sufficiently to get into a region of south dip of the magnetic needle. By noon of October 17, the third day after sailing from Fanning Island, we had reached a point about 90 miles south of the equator, where southerly dip of a very appreciable amount was observed, and the vessel's course was changed to the northward. Fourteen days later, October 31, we crossed the chain of rocks, reefs, and islets that extends in a west-northwesterly direction from the Hawaiian group, at a point about 600 miles to the westward of Honolulu. On November 7, 24 days after leaving Fanning Island, Honolulu was reached, the distance sailed being 2,963 nautical miles. During this passage the weather conditions were such that the ship was swung on 3 days; observations on courses were made on 20 days; on 1 day it was too stormy to observe; on 3 days there were calms; on 6 days it rained a great deal, but course observations were made; and on 20 days the Sun shone only at intervals, either between clouds or showers. During this passage all the rigging had to be set up; some of it twice.

24. During the stay of 4 days in Honolulu, additional observations were made at the Coast and Geodetic Survey magnetic observatory, the vessel was painted, the rigging was set up, the water-tanks were filled with fresh water, and additional subsistence stores were taken aboard. As bubonic plague was declared prevalent there at that time, and as the vessel went alongside the naval dock for

water and supplies, she was taken alongside the quarantine wharf on the last day of our stay, in order to obtain a clean bill of health and to be thoroughly fumigated with sulphur.

25. On the morning of November 12, 1905, the *Galilee* was towed out of Honolulu Harbor. Sailing to a point abreast of the Honolulu Magnetic Observatory at Sisal, we swung ship there, under sail, with both helms; at 5^h 30^m p. m. the swings were completed, and we started on a passage for San Diego, California. On the second day out the weather became nasty; by dark the sea had increased and by 8 o'clock it was blowing a moderate gale northeast. During the earlier portion of the night the jib blew away, then the fore weather-braces carried away; while taking in the mainsail, to reef it, its spreader became unmanageable and smashed a hole through the deck of the forward cabin; then the sheets of the flying jib carried away, and the upper and lower foretopsail weather-braces parted. A little later the storm increased to a gale, and the vessel was hove to under reefed mainsail, lower foretopsail, and a storm forestaysail, the vessel drifting in the meantime to the westward. The following day a moderate northeast gale continuing, with heavy seas, we hove to a greater portion of the day and were now in what is considered to be the belt of nasty weather that continues to the westward beyond Midway Island. The wind continued unfavorable in direction for 13 days after leaving Honolulu, but on November 26, when in the latitude of the northern boundary of California, we got a slant which continued, although very light at times, all the way to San Diego, where we arrived on the night of December 9, 1905. During this passage we were out from Honolulu 27 days, covering a distance of about 3,430 miles. If average weather of the season had been encountered, the passage would probably have been made in about 20 or 21 days. During this passage we experienced heavier weather than at any time during the cruise, and we had 2 days calm in the latitude of Northern California; the weather conditions were such that the ship was swung on 5 days, observations were made on course on 8 days, 2 days were calm, and during 10 days there was heavy weather.

26. Between December 11 and 18 the ship was swung with both helms at San Diego, in the same place as when we set out from this port. Complete observations for all the magnetic elements and constants were made ashore at the station selected and used before sailing from San Diego.

27. For the summary of passages for the cruise, see page 143.

28. During the portion of the cruise from San Diego back to San Diego, making a circuit of 9,931 nautical miles, observations of air and ocean-surface temperatures were made, tabulated, and plotted for intervals of every 4 hours.

29. After arrival in San Diego, the alinement of the instruments was carefully tested, with the result that the vertical planes of their respective keel-lines were all found to be parallel.

30. Many obligations are due to Captain H. W. Lyon, U. S. Navy, commandant of the naval station at Honolulu, who extended courtesies in many ways, including a berth for the *Galilee* at the naval docks on both occasions of our visit there.

31. During December 15 to 18 the vessel and work were inspected by the Director of the Department, and authorization was given for the changing of the forward house, lengthening of the flying bridge, and for other changes (see Instructions, page 118). On December 19, Dr. Egbert was relieved from duty on the vessel, and on the following day Mr. Whitney also was relieved, both of them returning to their duties in the Coast and Geodetic Survey. By December 21 the property returns had been checked off, foremen carpenters interviewed, and arrangements made for the proposed changes in the vessel, and on that date I left San Diego for San Francisco, leaving the vessel in charge of Observer Ault.

32. After arriving in San Francisco, details of the proposed changes were gone over by me with the managing owner of the vessel, and a definite understanding was reached. The changes as later made were as follows: About 8 feet of the after end of the forward deck house was cut off, *i.e.*, as far forward as the after one of the boat skids; the fore-hatch coamings were trimmed off; the hatchway was filled in and was decked over, and a new galley, about 7 feet by 14 feet, was built over the hatchway; the flying bridge was lengthened forward so as to reach within about 18 inches of the foremast; a new mast band was designed; the main stay was raised so that it would clear the new forward end of the bridge; the lower foretopsail sheets were changed from iron cable to hemp; the hauling part of the upper foretopsail halyards was changed from iron chain cable to hemp; and in the observers' cabin an additional stateroom was constructed. The execution of these changes was directed by me from San Francisco, Captain Hayes being in charge of the work at San Diego.

33. The new commander of the expedition, W. J. Peters, having the party in readiness, arrived in San Diego on February 9, 1906. The relative positions of the instruments remained unchanged from what they were between August 24 and December 20, 1905. For plan of the extended bridge see Fig. 1, Plan C, page 27, the initial point being as in all previous conditions the center of the sea dip-circle. Before swinging ship, I personally adjusted the instruments with much care for alinement. The change in the forward one was quite considerable, as the bridge, in splicing it out, had taken up some wind. The weather during February proved to be unusually bad (for San Diego) for swinging ship, there being a great deal of rain, interspersed with cloudy and foggy weather. The vessel was swung on February 14, 15, and 26, 1906, in the same place where the previous swings had been made. During these swings the vessel was in a normal condition, with the exception that on the last day the iron stern-davits were not in place, as they were ashore at a shop serving as patterns for making heavier ones to carry a gasoline launch. On February 27 I left San Diego, returning to my duties in the Coast and Geodetic Survey on March 1, 1906.

W. J. PETERS: DISCUSSION OF ALIDADE CORRECTION FOR STANDARD COMPASS R3C.[1]

There are many different styles of compasses and compass devices for obtaining the magnetic bearing of celestial and terrestrial objects. This discussion is based upon considerations of the Ritchie azimuth-circle with peep-sight, vertical thread, and dark mirror, referred to in this volume as "alidade method" (see *AB*, Pl. 3, Fig. 2). The principles are, however, applicable to any compass device which depends upon reflection by mirror or prism mounted on a horizontal axis to obtain the desired bearing.

Let D_e be the observed magnetic declination, obtained by the alidade method at some station where the standard declination at the same instant is D. Furthermore, let $-A_{ec}$ be the alidade correction to be applied to D_e to obtain D. Then

$$A_{ec} = D_e - D$$

If, when observing, the mirror axis of rotation is not truly horizontal, or if it is not perpendicular to the line of sight (from lower part of peep-sight to lower end of vertical thread of azimuth circle),[2] or again, if the axis does not lie in the plane of the mirror surface or is not parallel to it, then A_{ec}, as determined from observations with the mirror, will contain the combined effect of the conditions mentioned. If the separate effects are represented by a, b, c, respectively, then

$$A_{ec} = a + b + c + x = D_e - D$$

In this equation x is the part of A_{ec} which in no way depends upon the position of the mirror surface.

If the altitude of the Sun or object sighted is very small, the mirror is nearly horizontal and the line of sight from the eye, striking the mirror at an exceedingly small glancing angle, is but little affected by a faulty installation of the mirror, so that, for an altitude, $h = 0$, it may be assumed that $a + b + c = 0$.

For an altitude, $h = 180°$, the mirror is vertical, the first effect, a, disappears, and b and c attain their maximum values. a, b, c are functions of the altitude h, which are found from geometric considerations to be as follows:

$$a = y \tan h \qquad b = z \tan h \tan \frac{h}{2} \qquad c = w \tan h \sec \frac{h}{2}$$

The expression for A_{ec} becomes, accordingly

$$A_{ec} = x + y \tan h + z \tan h \tan \frac{h}{2} + w \tan h \sec \frac{h}{2} = D_e - D \tag{1}$$

[1]This designation applies to the standard Ritchie liquid compass 29499 provided with azimuth circle 481-III. R3C was used on Cruise III of the *Galilee* (see pp. 31 and 62).

[2]To avoid circumlocution, the expression "peep-sight and vertical thread" is used to denote this line, and "plane of apparent bearing" defines the vertical plane that contains this line.

Each observation will give a similar equation, and the most probable values of x, y, z, and w may be found from all the observations by the method of least squares.

In the case of the "alidade method," the number of unknowns may be reduced by methods given below, where each unknown is separately considered.

x, its significance and value.—x in this discussion, represents the combined results of —

(1) Non-coincidence of the axis of the magnetic system with the zeros of the card;
(2) The vertical plane containing the optical ray, peep-sight and vertical thread, not passing through center of card;
(3) Lack of horizontality of reading prism (that is, the optical ray from peep-sight to reading thread of prism may not be reflected perpendicularly on to the plane of the card graduations);
(4) The vertical thread and the reading thread of reading prism may not lie in the same vertical plane;
(5) Errors of graduation (in some instruments errors have been found amounting to as much as 0°.3);
(6) Eccentric mounting of the pivot;
(7) Altered balance of compass card owing to extreme values of the vertical intensity of the magnetic field.

The value of x may be determined from declination observations at land stations where simultaneous standard values are available for comparison, and where it is possible to have azimuth marks fairly well distributed around the horizon. If the compass bowl is turned or oriented during observations on these marks, so as to set the forward lubber-line at any 3 or more equidistant points, *e. g.*, the cardinal points, the mean result of the declination from the pointings on any one mark in the equidistant orientations will be free from errors of eccentricity of pivot. A comparison of these mean results with the corresponding standard values of the declination will give a value of x for the bearing of each mark. A graph may be constructed or a table calculated from these results, by which any compass-bearing of an object in the horizon may be corrected. The differences between the individual values of x and the mean of all are the periodic and graduation errors. The non-coincidence of the axis of the magnetic system with the zeros of the card, lack of horizontality of the reading prism, and any error in the assembling of vertical thread and reading thread of the prism may be considered constant for all practical purposes, and this combined effect is assumed to be the mean of all observations made for the purpose of determining x. Therefore, during the remainder of this discussion, x may be considered as determined or known, and represented by x_o. Equation (1) may then be written

$$y \tan h + z \tan h \tan\frac{h}{2} + w \tan h \sec\frac{h}{2} = D_o - D - x_o \qquad (2)$$

which contains but three unknowns.

In the following demonstrations it is assumed that the azimuth circle revolves about an axis which is perpendicular to the compass-bowl glass, since the instrument is leveled by a circular level resting on this surface. This condition may be verified by placing the instrument on a solid pier or otherwise making it immovable and then observing two circular levels while the azimuth circle is being rotated, one resting on the bowl-glass surface, the other on the circle.

$a = y \tan h$.—If the dark mirror is in perfect adjustment, as it rotates about its axis a normal to its surface will move in a vertical plane (EZH, Fig. 5), which contains the line "peep-sight and vertical thread," and hence also the object sighted. The intersection of this plane with the horizon plane is the apparent and also the true azimuthal direction. Figure 5 is an orthographic projection upon the plane of the horizon. If the mirror axis is inclined to the horizon plane by a small angle, y, the plane $EOHPS$, now described by a normal to the mirror surface as it rotates about its inclined axis, no longer passes through

the zenith, but passes to one side by an angular distance $(ZY) = y$. However, the plane contains the line "peep-sight and vertical thread," EOH, which is the apparent azimuthal direction of an object, S, in this inclined plane. But the true azimuthal direction of S is determined by the horizontal trace of a vertical plane ZOS passing through it, and the correction a is the angle SZH between this vertical plane and a vertical plane containing the line "peep-sight and vertical thread."

From the spherical triangle, SZH, there results

$$\frac{\sin SZ}{\sin SHZ} = \frac{\sin SH}{\sin SZH}$$

or

$$\sin a = \frac{\sin SH}{\sin SZ} \sin SHZ = \frac{\cos SZ \sin y}{\sin SZ \cos y}$$

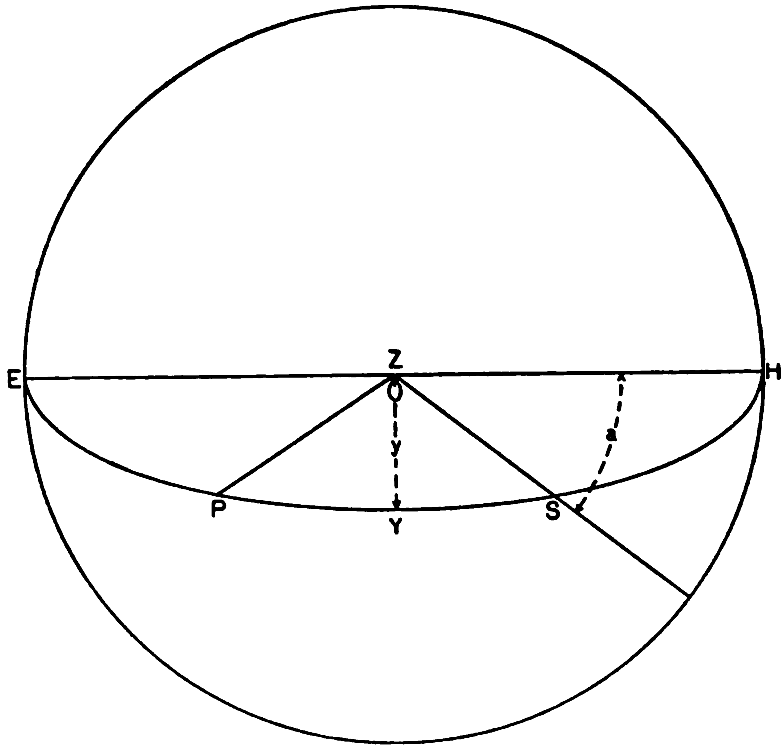


FIG. 5.

but as $SHZ = y$ is less than 1° in instruments constructed with ordinary care, the arcs may be substituted for sin a and tan y; introducing h, this equation becomes

$$a = y \tan h$$

It is to be noted that if h is reckoned through the zenith when the Sun is behind the observer, the formula may be considered general, so, when $h = 0°$ or $180°$, $a = 0$, and when $h = 90°$, a becomes infinite, and for $h > 90°$, tan h is negative.

Let the mirror be made parallel to a line in the surface of the compass-bowl glass, which line in turn is parallel to the line "peep-sight and vertical thread," that is, let the mirror be rotated about its axis to a horizontal position. Next turn the azimuth circle until the direction to a very distant object is at right angles to the line "peep-sight and vertical thread." Then, if angular measures are made with sextant or theodolite between this distant object and its reflections, as given by the mirror and compass-bowl glass, respectively, one-half the

difference of these two measures is the angle between the mirror surface and compass-bowl surface, and is the combined effect of y and w. So that, if m represents this effect, then

$$m = y + w \text{ or } y = m - w$$

which, substituted in equation (2), gives

$$m \tan h - w \tan h + z \tan h \tan \frac{h}{2} + w \tan h \sec \frac{h}{2} = D_e - D - x_e \tag{3}$$

which contains but two unknowns, when m has been determined.

$b = z \tan h \tan \frac{h}{2}$.—If the only error in the mirror adjustment is that which results

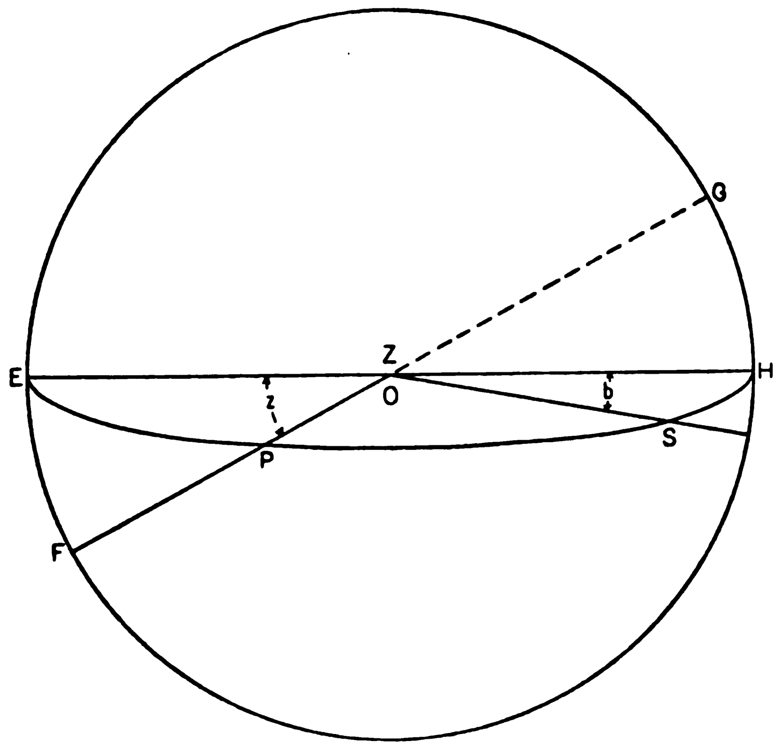


FIG. 6.

when the mirror axis is not perpendicular to the line "peep-sight and vertical thread," then as the mirror is rotated, a normal to its surface moves in a plane $FOGZ$, Figure 6, passing through the zenith and making a constant angle, z, with the line "peep-sight and vertical thread." It intersects the celestial sphere in a great circle $FPZG$. For a particular altitude, h, the normal, OP, to the mirror surface, intersects this circle in a point P, at a distance from the zenith Z equal to $\frac{h}{2}$. The Sun is found in a plane, $EPSH$, containing the "peep-sight and vertical thread," EO, and the normal, OP. The error, b, is the angle SZH between the vertical plane ZS, through the Sun, and the vertical plane EOH, containing the line "peep-sight and vertical thread."

The quadrantal triangle, PZE, gives

$$\tan PEZ = \sin PZE \tan PZ = \sin z \tan \frac{h}{2}$$

The triangle, SZH, as before, gives

$$\sin SZH = \tan SHZ \tan h$$

but SHZ is equal to PEZ, hence when z is small

$$b = z \tan h \tan \frac{h}{2}$$

If the altitude is reckoned through the zenith for the Sun behind the observer, the formula is general; so, when $h = 0°$, $b = 0$, and when $h = 180°$, b, evaluated, $= -2z$, which evidently agrees with the physical fact.

$c = w \tan h \sec \frac{h}{2}$.—If, during Sun observations, the dark mirror is in perfect adjustment, a normal to the surface will move in a vertical plane which contains the line "peep-sight and vertical thread," EO, and hence also the Sun. This plane, whose horizontal trace is the Sun's azimuthal direction, intersects the celestial vault in a great circle EZH (Fig. 7). If the axis of the mirror is horizontal and perpendicular to the line "peep-sight and vertical thread," but does not lie in the plane of the mirror surface or parallel to it

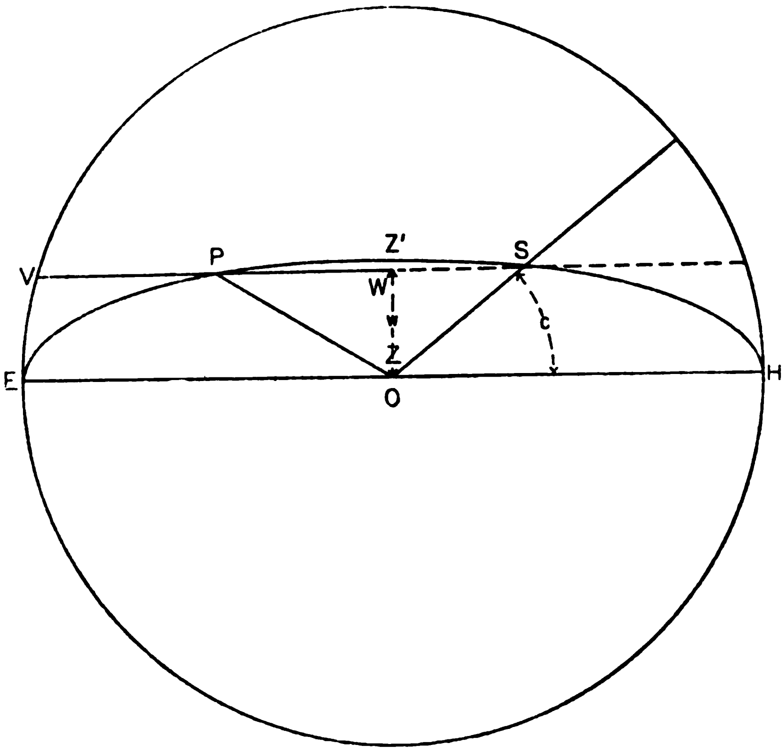


FIG. 7.

(*i. e.*, "the mirror is not true in the frame"), the normal no longer describes a plane, but the surface of a broad cone, which intersects the celestial vault in a small circle VW, parallel to the great circle EZH, and at an angular distance, w, from it, measured by the arc WZ. The Sun is now found in a plane $EPZ'SHO$, which contains the line "peep-sight and vertical thread," the normal, and the Sun. This plane forms an angle $SHZ = PEZ$ with the plane of the apparent azimuth. Since the normal PO bisects the angle between the incident ray SO and the reflected ray OE, $PZ' = \frac{1}{2}SH$, or $PE = 90° - \frac{1}{2}SH$. From the right-angled spherical triangle with PE as hypothenuse, formed by drawing an arc from P perpendicular to EZ, equal in length to w, $\sin PEZ = \sin SHZ = \sin w \sec \frac{1}{2} SH$.

In the spherical triangle SHZ, $\sin SZH = \sin c = \frac{\sin SH}{\sin SZ} \sin SHZ$, hence,

$$\sin c = \sin w \frac{\sin SH}{\sin SZ} \sec \tfrac{1}{2} SH = \sin w \frac{\sin SH}{\cos h} \sec \tfrac{1}{2} SH$$

When w is small, c is also small, and SH does not differ appreciably from h, hence this equation may be written

$$c = w \tan h \sec \frac{h}{2}$$

If h is reckoned through the zenith, the formula becomes general, so for $h = 180°$ there results, when evaluated, $c = -2w$, which agrees with the physical fact.

Let the mirror be turned on its axis until its surface is vertical, or so nearly so that the reflected image of the peep-sight may be observed through the peep-sight. Then, if this image does not coincide with the vertical thread, the displacement may be measured by reading a white scale held against the peep-sight. This displacement is equal to the combined effects of z and w and may be represented by the equation

$$2n = 2(z + w)$$

The ratio of this displacement to the distance between the mirror surface and peep-sight is $\tan 2n$.

Since n may be determined from direct linear measurements, $z = n - w$ may be substituted in equation (3), which gives

$$w = -\frac{D_e - D - x_e - m \tan h - n \tan h \tan \frac{h}{2}}{\tan h + \tan h \tan \frac{h}{2} - \tan h \sec \frac{h}{2}} \qquad (4)$$

The equation now contains but one unknown, w, which varies with the altitude and which may be determined from solar observations. It is evident that the best determination of w will result from those observations which give a large numerical value to the denominator; hence only high Sun observations should be used to determine w from this equation.

Application of Preceding Theory to Measures Made at Honolulu, September 6 and 7, 1907.

$m = y + w$ for standard compass R3C was measured at the Honolulu Magnetic Observatory, and its value was found to be $-0\overset{\circ}{.}10$. The sign was determined by considering the relative size of the angles between the distant object and its images in the compass-bowl glass and mirror. It was found that the normal was deflected to the left when looking in the direction "peep-sight and vertical thread" (*i. e.*, the direction used in observing). Therefore, any observed compass-bearing of a high Sun was too great (clockwise). If a_e be the observed bearing, always clockwise from the south point, and a the true azimuth, then

$$D_e = a - a_e$$

In this equation, if a_e is too great, D_e is small as compared with D, so in the equation

$$A_{ec} = D_e - D$$

if D_e is smaller than D, because the normal is deflected to the left, then that part of A_{ec} which is due to this deflection is negative.

The linear displacement due to $2n = 2\,(z + w)$, was measured on board ship by a scale held against the peep-sight and was found to be 4.75 mm. The distance between the mirror and peep-sight is 226 mm., and since the image of the peep-sight was deflected to the apparent right,

$$\tan 2n = \tan 2\,(z + w) = -\frac{4.75}{226}$$

$$\text{or } n = -0^\circ\!.60$$

The sign was verified by actual experiment. Using a small sextant mirror, it was found that if it was turned so as to deflect the peep-sight image to the right the bearings were too large (clockwise).

The values of y, z, and w as finally determined from a least-square adjustment of all observations made with this instrument, are the respective numerical coefficients in the following equation:

$$A_{as} - x_s = -1^\circ\!.682 \tan h - 1^\circ\!.173 \tan h \tan\frac{h}{2} + 1^\circ\!.750 \tan h \sec\frac{h}{2}$$

The observed values of A_{as}, h, and the weights p assigned in the above-mentioned least-square adjustment are tabulated below, together with the differences between the observed values of A_{as} and those obtained by computation from the derived formula. These differences are given in the column headed $O-C$.

TABLE 41.—*Portion of Alidade Corrections for Standard Compass RSC Dependent on Altitude.*

No.	Station	Date	Sun's alt. (h)	($A_{as}-x_s$) Obs'd	Comp'd	$O-C$	p
		1906	°	°	°	°	
1	San Diego.......	Dec. 14	33	−0.11	−0.13	+0.02	2
2	Do.........	Dec. 15	9	+0.06	0.00	+0.06	2
		1907					
3	Papeete, Tahiti..	Feb. 9	55	−0.45	−0.46	+0.01	1
4	Do.........	Feb. 9	64	−0.99	−0.72	−0.27	½
5	Do.........	Feb. 12	36	−0.23	−0.16	−0.07	½
6	Do.........	Feb. 12	24	−0.11	−0.06	−0.05	2
7	Yap...........	Apr. 16	16	−0.08	−0.02	−0.06	2
8	Do.........	Apr. 17	52	−0.45	−0.39	−0.06	2
9	Do.........	Apr. 17	23	−0.14	−0.06	−0.08	2
10	Woosung........	May 20	17	−0.03	−0.03	0.00	2
11	Do.........	May 20	51	−0.43	−0.37	−0.06	2
12	Do.........	May 25	32	−0.17	−0.12	−0.05	2
13	Do.........	May 25	9	−0.03	0.00	−0.03	2
14	Sitka..........	July 20	50	−0.35	−0.36	+0.01	1
15	Do.........	July 20	47	−0.23	−0.31	+0.08	1
16	Do.........	July 20	23	+0.03	−0.06	+0.09	1
17	Do.........	July 20	16	−0.01	−0.02	+0.01	2
18	Honolulu........	Sept. 6	14	−0.04	−0.02	−0.02	2
19	Do.........	Sept. 7	11	+0.03	−0.01	+0.04	2
20	Do.........	Sept. 7	44	−0.19	−0.26	+0.07	2
21	Jaluit..........	Oct. 29	10	+0.02	0.00	+0.02	2
		1908					
22	Christchurch....	Jan. 4	63	−0.57	−0.68	+0.11	2
23	Do.........	Jan. 4	44	−0.38	−0.26	−0.12	2
24	Do.........	Jan. 4	21	+0.13	−0.05	+0.18	2
25	Callao.........	Mar. 17	34	−0.05	−0.14	+0.09	2
26	San Francisco...	May 20	10	+0.02	0.00	+0.02	2

ABSTRACTS OF LOGS OF THE GALILEE.

J. F. PRATT: ABSTRACT OF LOG, CRUISE I, 1905.[1]

SAN FRANCISCO TO SAN DIEGO, CALIFORNIA.

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1905	° ′	° ′	*miles*	
Aug. 5	San Francisco	....	....	2 p. m. left San Francisco.
6	36 30 N.	235 13	134	Gentle to moderate breezes from W. Cloudy and misty.
7	34 55 N.	238 13	174	Moderate breezes from NW. by N. Overcast.
8	32 49 N.	239 00	132	Light variable airs. Overcast.
9	32 52 N.	240 10	59	Light airs to light breezes from W. Cloudy and foggy.
10	33 09 N.	241 47	83	Light to gentle breezes from W. Partly cloudy. Swung ship under sail.
11	San Diego	....	58	Light to gentle breezes from W. Fine weather. Swung ship under sail. 4h 30m p. m. anchored in harbor of San Diego.

Total distance, 640 miles. Time of passage, 6.1 days. Average day's run, 105.0 miles.

SAN DIEGO, CALIFORNIA, TO HONOLULU, TERRITORY OF HAWAII.

1905	° ′	° ′	*miles*	
Sept. 1	San Diego	....	....	1 p. m. left San Diego. Light airs from WSW. to W. Moderate head swell. Clear Weather.
2	31 32 N.	241 47	84	Light airs to moderate breeze from W. to WNW. Moderate head sea. Cloudy to partly cloudy.
3	29 26 N.	238 55	194	Moderate breezes from NW. Moderate head sea. Partly cloudy to cloudy.
4	28 44 N.	235 44	172	Moderate breezes from NW. to NNW. Overcast.
5	28 23 N.	232 16	184	Gentle to moderate breezes from N. Sea moderate. Cloudy.
6	28 01 N.	228 43	189	Gentle breezes from N. Sea moderate. Cloudy, with passing showers.
7	27 39 N.	225 22	179	Gentle breeze from NNE. with moderate following sea. Overcast.
8	27 19 N.	222 42	143	Light to gentle breezes from NE. Sea moderate. Overcast.
9	26 52 N.	220 43	109	Light airs from NE. Overcast followed by clearing weather.
10	26 11 N.	218 16	138	Light to moderate breezes from NE. with heavy following swell. Cloudy, with passing showers, followed by clear sky. Ship rolling.
11	25 29 N.	215 56	133	Moderate breeze from NE. Clear to cloudy. Swung ship under sail. Logs hauled in during swing. Ship rolling considerably.
12	24 36 N.	213 36	138	Variable breezes. Light showers, followed by clear weather. Moderate following ground swell. Swung ship in p. m.
13	24 00 N.	211 07	141	Moderate breezes from NE. Moderate following ground swell. Clear.
14	23 00 N.	208 22	163	Moderate breezes from NE. Moderate swell. Partly cloudy.
15	21 38 N.	204 31	229	Moderate to stiff breezes from NE. with heavy following sea. Clear to cloudy.
16	Honolulu	....	135	8h 15m a. m. docked at Honolulu. Partly cloudy.

Total distance, 2,331 miles. Time of passage, 14.8 days. Average day's run, 157.5 miles.

HONOLULU, TERRITORY OF HAWAII, TO FANNING ISLAND.

1905	° ′	° ′	*miles*	
Sept. 28	Honolulu	....	....	1h 30m p. m. left dock at Honolulu. Variable winds. Clear weather. Swung ship off Barber's Point by tug.
29	19 57 N.	....	Becalmed	Calm, with no headway all day.
30	19 35 N.	202 55	112	Calm, with no headway all day.
Oct. 1	19 23 N.	203 14	22	Calm and light variable airs. West wind at 8 p. m.
2	17 48 N.	203 48	100	Fresh breezes from E., with rain squalls. Heavy sea. Clear to partly cloudy.
3	14 50 N.	204 22	181	Moderate to stiff breezes with heavy swells from E. Clear to cloudy, with squalls.
4	11 01 N.	204 52	231	Variable winds with rain squalls, passing showers and lightning.
5	9 14 N.	204 42	107	Calm and light variable airs. Heavy rain squalls. No steerage at times.
6	7 29 N.	204 28	106	Light breezes from NNE. Cloudy with heavy rain showers; partly clear in afternoon.
7	6 04 N.	204 04	88	Light to gentle breezes from SE. Fine weather.
8	4 11 N.	201 34	187	Gentle breezes from SE. Clear weather.
9	4 24 N.	201 05	32	Light airs from SSE. Clear sky. Fine weather.
10	Fanning Island	......	41	2 p. m. made fast to mooring-buoy off cable station at Fanning Island. Light breezes from NE. Clear sky.

Total distance, 1,207 miles. Time of passage, 12.0 days. Average day's run, 100.6 miles.

[1] For report on this cruise, see pages 128–134; also p. 10.

FANNING ISLAND TO HONOLULU, TERRITORY OF HAWAII.

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1905	° ′	° ′	*miles*	
Oct. 14	Fanning Island			Swung ship. 7^h 30^m p. m. let go mooring-buoy at Fanning Island.
15	2 19 N.	200 35	96	Light airs to fresh shifting breezes. Heavy rain squalls. Clear, then cloudy.
16	0 14 N.	198 35	173	Gentle to moderate breezes from SSE. to ESE. Cloudy, with passing showers, followed by fine steady weather.
17	1 30 S.	197 14	132	Gentle breezes from E. and NE. Fine weather.
18	0 20 N.	195 34	149	Moderate breezes to light airs from NNE., diminishing. Clear sky.
19	1 24 N.	194 00	114	Light airs from NE. to ESE. Clear sky. .
20	2 36 N.	194 00	72	Light airs from SE. to S. Partly cloudy, with passing showers p. m.
21	3 08 N.	194 36	48	Gentle breezes to light airs from S. to SSE. Rain squalls a. m. Cloudy.
22	4 28 N.	195 53	111	Light breezes from SE. to ESE. Cloudy weather, but clearing at night.
23	6 39 N.	196 09	132	Light breezes from NE. Fine clear weather.
24	8 46 N.	195 28	133	Moderate breezes from NNE. to ESE. Moderate swells from NE. Partly cloudy. Rain squalls.
25	11 46 N.	194 33	188	Moderate to stiff breezes from NE. Moderate swells from NE. Clear.
26	14 53 N.	192 47	214	Moderate to stiff breezes from NE. Clear sky.
27	17 31 N.	191 37	172	Gentle to moderate breezes from NE. to ENE. Blue sky to cloudy with passing showers. Observations interrupted by squalls.
28	19 51 N.	190 55	145	Moderate breezes from ENE. to NNE. Clear blue sky.
29	22 37 N.	190 31	168	Light breezes from E. Clear, fine weather.
30	24 15 N.	191 07	103	Light breezes from SE., diminishing to calm. Clear blue sky. No headway after noon. Quantities of small drift on surface.
31	24 14 N.	191 06	1	Calm to light breeze from NE. Cloudy to partly cloudy. No headway a. m.
Nov. 1	25 09 N.	191 08	55	Light airs from SE. to S., followed by calm. Fine clear weather.
2	25 37 N.	192 40	88	Gentle breezes from S. Cloudy weather, clearing in afternoon.
3	25 47 N.	195 47	169	Moderate to stiff breezes from SSE. Dark, stormy-looking weather, with passing showers.
4	25 44 N.	199 07	180	Variable winds. Overcast and cloudy, with rain and squalls.
5	24 32 N.	199 48	81	Moderate breezes from N., with heavy following ground swell. Cloudy, with passing showers.
6	23 08 N.	201 25	122	Gentle breeze from NNE. Clear to cloudy, with passing showers of rain.
7	Honolulu		117	5^h 30^m p. m. docked at Honolulu. Gentle breezes from NE. Clear weather.

Total distance, 2,963 miles. Time of passage, 23.9 days. Average day's run, 124.0 miles.

HONOLULU, TERRITORY OF HAWAII, TO SAN DIEGO, CALIFORNIA.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1905	° ′	° ′	*miles*	
Nov. 12	Honolulu			8 a. m., left wharf under tow. Moderate breezes from NE. Fine weather.
13	23 07 N.	201 14	120	Moderate breezes from ENE. Small sea. Clear weather. Swung ship.
14	24 21 N.	201 08	74	Moderate to fresh breezes from N. to N. by E. Heavy sea. Clear to cloudy, with passing showers and squalls.
15	25 09 N.	199 19	110	Fresh breezes to strong gales, with heavy seas from NE. Cloudy, passing showers and wind squalls.
16	26 40 N.	197 54	119	Moderate breezes from NE. Cloudy, with passing showers.
17	28 14 N.	196 29	121	Light breezes from NE. to E., diminishing. Clear sky. Swung ship.
18	29 33 N.	196 46	80	Gentle breezes from E. to SE. Clear to overcast and cloudy, with rain.
19	31 29 N.	199 44	192	Gentle to mod. breezes from SSE. Heavy swells from SSE. Cloudy, rain.
20	32 26 N.	203 46	213	Moderate breezes from SSE. Rough sea. Partly cloudy weather.
21	33 26 N.	207 15	185	Moderate breezes to calm from SE. to E., followed by moderate breezes from ENE. Heavy sea. Overcast and rainy weather.
22	36 13 N.	206 31	171	Moderate to stiff breezes from ENE. to E. Heavy swell from E. Ship laboring. Clear to cloudy.
23	39 23 N.	208 25	210	Moderate breezes to light airs from ESE. Cloudy to clear.
24	40 38 N.	209 09	82	Light airs from E. to calm. Clear weather with heavy dew. Swung ship.
25	41 06 N.	209 19	29	Clear and calm weather. Smooth sea. Small swell from east.
26	41 11 N.	209 40	17	Calm to light breezes from SSE. Clear to partly cloudy.
27	40 40 N.	213 02	156	Gentle to moderate breezes from SSW. Rapid rise in water temp. Cloudy.
28	39 25 N.	218 22	256	Moderate to stiff breezes, SSW. to NW. Overcast and cloudy, with rain to partly cloudy. Heavy swell from WNW.
29	37 53 N.	222 26	212	Moderate to light breezes from NW. Cloudy to partly cloudy.
30	37 16 N.	224 12	92	Light variable airs and heavy swell. Partly cloudy to cloudy.
Dec. 1	36 45 N.	227 57	182	Moderate to light breezes from S. Overcast and cloudy.
2	36 32 N.	230 36	128	Light airs from SW. to calm. Partly cloudy. Glassy sea at night.
3	35 58 N.	231 45	65	Gentle breezes from N. to NNE. Small swells from W. Partly cloudy.
4	35 54 N.	234 26	130	Light airs from NNE. to calm. Smooth sea. Partly cloudy. Ship swung.
5	34 20 N.	235 32	108	Light variable airs from NNE. and N. Smooth sea. Partly cloudy.
6	33 34 N.	237 09	104	Light to gentle breezes from NW. to NNW. Smooth sea. Partly cloudy.
7	33 14 N.	239 53	125	Gentle breezes from NNW. Smooth sea. Cloudy to partly cloudy.
8	32 58 N.	241 17	72	Light variable airs to calm. Clear to partly cloudy.
9	San Diego		77	3 p. m. arrived off quarantine dock, San Diego. Moderate breeze to light airs from NNE.

Total distance, 3,430 miles. Time of passage, 27.3 days. Average day's run, 125.6 miles.

Summary of Passages for Cruise I of the Galilee.

TABLE 42.

Passage	Length of passage	Time of passage	Average day's run
	miles	*days*	*miles*
San Francisco to San Diego.......	640	6.1	105
San Diego to Honolulu...........	2,331	14.8	158
Honolulu to Fanning Island......	1,207	12.0	101
Fanning Island to Honolulu......	2,963	23.9	124
Honolulu to San Diego...........	3,430	27.3	126
Total....................	10,571	84.1	126

W. J. PETERS: ABSTRACT OF LOG, CRUISE II, 1906.[1]

SAN DIEGO TO FANNING ISLAND.

Date	Noon position				Day's run	Remarks
	Lat.		Long. E. of Gr.			
1906	°	′	°	′	*miles*	
Mar. 2	San Diego.					$3^h 30^m$ p. m., left dock at San Diego.
3	32	23 N.	242	38	17	Light airs from S. Clear. Clouds later interrupted attempt to swing by launch.
4	31	27 N.	241	10	93	Moderate breezes from NW. by W. to WNW.
5	29	09 N.	238	09	209	Gentle breezes from NW. by W. to N. Partly cloudy to cloudy. Swung ship under sail, both helms.
6	27	54 N.	236	04	133	Calm to light airs from NE. Cloudy to partly cloudy.
7	27	12 N.	234	56	73	Calm to light airs from E. to NNE. Cloudy to blue sky and cloudy. Swung ship.
8	26	23 N.	233	49	77	Light breeze from N. by W. Clear day.
9	25	58 N.	232	56	54	Calm to light breezes from S. Clear to cloudy. Swung ship by launch.
10	25	54 N.	230	29	132	Stiff breezes from S. Cloudy. Heavy squalls during night.
11	27	42 N.	228	58	135	Stiff breezes from SW. Rough sea. Occasional squalls. Cloudy.
12	26	43 N.	227	11	112	Gentle breezes from NW. Rough sea. Clear to cloudy.
13	25	37 N.	226	17	82	Calm. Heavy cross swells. Clear to cloudy.
14	25	08 N.	225	16	62	Light airs to gentle breezes from SE. Clear sky. Swung ship with both helms.
15	24	38 N.	223	45	88	Light airs from SE. and calm. Clear to partly cloudy.
16	24	18 N.	222	57	48	Light airs to gentle breezes from SE. Partly cloudy.
17	22	23 N.	220	02	198	Moderate to stiff breezes from SE., W., and NW. Cloudy, with heavy rain squalls from W.
18	22	07 N.	218	12	103	Moderate breezes from S. by W. and calm. Cloudy. Rain squalls p. m.
19	20	25 N.	217	34	108	Gentle breezes from W. by S. to W. Clear to cloudy. Pitching into head sea.
20	19	01 N.	217	31	84	Calm to light airs from WNW. Heavy cross swells. Partly cloudy. Rolling badly.
21	18	06 N.	216	53	66	Light airs to light breezes from NE. and E. Partly cloudy. Swung ship on 7 headings, both helms.
22	16	58 N.	215	10	120	Gentle breezes from SE. and calm. Clear to partly cloudy.
23	16	25 N.	214	32	49	Light airs from SE. and calm. Clear, becoming partly cloudy.
24	15	29 N.	213	18	91	Light to moderate breezes from ENE. to NE. Partly cloudy. Swung ship on 12 headings, both helms.
25	14	13 N.	211	42	119	Light to moderate breezes from NE. to E. Partly cloudy, becoming clear.
26	12	28 N.	209	35	162	Light to moderate breezes from NE. Partly cloudy, becoming clear.
27	10	23 N.	207	45	165	Moderate breezes from NE. Partly cloudy. Attempted swing; too rough.
28	7	49 N.	205	56	188	Moderate breezes from NE. Rough sea. Cloudy. Rain.
29	5	16 N.	203	40	204	Moderate to stiff breezes from NE. Partly cloudy. Clearing.
30	Fanning Island......				200	5 p. m., anchored off Fanning Island.

Total distance, 3,172 miles. Time of passage, 28.1 days. Average day's run, 112.9 miles.

[1]For synopsis of this cruise, see pages 11–12.

FANNING ISLAND TO APIA, VIA PAGO PAGO, SAMOAN ISLANDS.

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1906	° ′	° ′	*miles*	
Apr. 11	Fanning Island	......	....	Left 4^h 30^m p. m. Light to gentle breeses from NE. Partly cloudy.
12	2 12 N.	200 08	107	Gentle to mod. breezes from NE. to E. Partly cloudy to clear. Swung ship.
13	0 01 S.	199 23	141	Gentle to moderate breezes from SE. to E. Cloudy to clear.
14	3 10 S.	198 22	199	Moderate breezes from ESE. Clear to cloudy.
15	6 08 S.	197 53	180	Gentle breezes from ESE. Clear to cloudy.
16	7 05 S.	196 56	80	Calm to light breezes from SE. Clear. Swung ship.
17	8 18 S.	196 13	85	Light airs to light breezes from SE. to ESE. Cloudy to clear.
18	9 18 S.	195 55	63	Calm to light airs from SE. Rain. Clear to cloudy.
19	10 12 S.	195 53	54	Light to moderate breezes from NW. Rain. Partly cloudy.
20	12 20 S.	195 06	136	Moderate breezes from W. to SW. Clear.
21	13 04 S.	194 12	69	Light breezes from NW. and calm. Rough sea. Cloudy to clear.
22	13 19 S.	193 55	22	Gentle breezes from NW. to N. Clear to cloudy.
23	14 00 S.	192 54	72	Light airs from NW. and calm. Cloudy to clear.
24	14 10 S.	192 59	11	Light airs from S. by E. and calm. Clear.
25	14 13 S.	191 41	76	Gentle to moderate breezes from SE. Clear.
26	Pago Pago	....	139	10^h 30^m a. m. dropped anchor. Gentle breezes from SE. Clear.
May 1	Pago Pago	....	....	5^h 15^m p. m. towed out of harbor at Pago Pago. Moderate breezes from SE.
2	Apia......	....	68	9 a. m. anchored at Apia. Gentle breezes from SE. Clear.

Total distance, 1,502 miles. Time of passage, 15.4 days. Average day's run, 97.5 miles.

APIA, SAMOAN ISLANDS, TO SUVA, FIJI ISLANDS.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1906	° ′	° ′	*miles*	
May 10	Apia	....	....	Left 9^h 30^m a. m. Moderate breeze from SE. to S. and calm. Clear to cloudy.
11	13 26 S.	185 26	166	Stiff breeze from SE. Clear to cloudy, with rain. Rough sea.
12	15 19 S.	182 04	225	Stiff to fresh breeze from NE. to SE. and gale from S. Cloudy, squally, rain.
13	16 07 S.	180 59	79	Gentle to mod. breeze from SE. to SW. Rough sea. Cloudy to clear blue sky.
14	16 33 S.	180 59	26	Gentle to moderate breeze from SE. to S. Clear weather. Ship pitching and rolling in rough sea.
16	18 01 S.	179 34	120	Crossed 180th meridian at 6 a. m. Gentle SE. breeze. Light rain, then clear.
17	Suva	....	66	12^h 10^m p. m. anchored in Suva harbor. Light breeze from NE. Cloudy.

Total distance, 682 miles. Time of passage, 6.1 days. Average day's run, 111.8 miles.

SUVA, FIJI ISLANDS, TO JALUIT, MARSHALL ISLANDS.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1906	° ′	° ′	*miles*	
May 26	Suva......	....	....	8 a. m. left anchorage at Suva under sail. Stiff breeze from E. Cloudy.
27	16 42 S.	176 06	157	Fresh breeze from E. to SE., increasing to a gale. Very rough sea. Cloudy, with light rains.
28	14 47 S.	176 49	122	Stiff breeze from SE. to E. Overcast, with light rains.
29	13 17 S.	177 08	92	Moderate breeze from E. Clear, cloudy at evening.
30	10 48 S.	176 45	151	Gentle breeze from NE., next light airs from N. by W. and W. Cloudy, rains.
31	10 29 S.	177 05	27	Light airs from E. Overcast to clear. Calm.
June 1	9 33 S.	178 07	83	Light breezes from ESE. to E. Cloudy.
2	8 56 S.	178 52	58	Light SE. breeze, next calm. Overcast, with light rains. Clear in evening.
3	8 38 S.	179 38	49	Light airs to light breezes from W. Clear.
4	8 08 S.	180 13	46	Light breeze from NW. Smooth sea. Clear. Swung ship, launch ahead.
5	7 17 S.	180 47	61	Calm to gentle breezes from ESE. Overcast, with rain, then clear.
6	5 50 S.	181 04	89	Gentle to moderate breeze from E. Clear.
7	4 30 S.	180 28	88	Moderate breeze from ESE. Clear weather, followed by rain. Swung ship.
8	2 45 S.	179 46	113	Stiff breeze from NE. Cloudy, with rain squalls and rough sea.
9	1 32 S.	178 10	120	Calm. Clear. Swung ship on 8 headings, both helms, launch assisting.
10	1 09 S.	178 24	27	Light breeze from SE to calm. Clear, becoming cloudy p. m.
11	0 37 S.	178 24	32	Gentle breezes from SE. to ENE. Clear. Smooth sea.
12	1 11 N.	177 56	112	Gentle breeze from ENE. to NE. Smooth sea. Clear. Swung ship a. m.
13	2 37 N.	176 48	110	Calm to light airs from NE. Partly cloudy, with occasional squalls.
14	3 23 N.	176 04	64	Light ESE. to SE. breeze and calm. Partly cloudy, passing showers.
15	3 57 N.	175 19	56	Light airs from SE. to calm. Clear, becoming cloudy. Ship rolling heavily.
16	4 02 N.	175 14	7	Light breeze from S. and calm. Clear. Rolling moderately.
17	4 35 N.	174 32	53	Light airs from NE. Rain squalls, followed by clear weather.
18	4 59 N.	173 25	71	Calm to moderate breeze from NNE. Cloudy, with squalls and rain.
19	5 21 N.	171 46	101	Moderate breeze from SE., followed by calm and light variable airs. Heavy rain and passing showers.
20	6 00 N.	170 21	93	Gentle to moderate breezes from E. by N. to NE. Cloudy to clear. Swung ship under sail 6 points, both helms.
21	Jaluit.....	....	42	10^h 30^m a. m. anchored off Jaluit.

Total distance, 2,024 miles. Time of passage, 26.1 days. Average day's run, 77.5 miles.

JALUIT, MARSHALL ISLANDS, TO GUAM.

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1906	° ′	° ′	*miles*	
June 30	Jaluit....	....	....	7h 15m a. m., left anchorage at Jaluit. Moderate breeze from NE. Clear.
July 1	7 00 N.	166 10	218	Gentle to light breeze from E. to S. Cloudy, with rain squalls. Ship rolling heavily.
2	7 15 N.	165 06	65	Light to moderate breeze from NE. Clear to partly cloudy. Ship rolling.
3	7 56 N.	162 39	151	Moderate breeze from ENE. Clear. Swung ship a. m. Ship rolling and pitching considerably.
4	8 49 N.	159 28	196	Gentle to moderate breeze from NE. Clear to cloudy.
5	9 52 N.	157 02	157	Calm and gentle breeze from NE. Partly cloudy.
6	10 31 N.	155 09	118	Gentle to moderate breeze from NE. Cloudy to clear. Swung ship a. m.
7	11 46 N.	152 15	186	Moderate to stiff breeze from NE. to E. Heavy rain, followed by light rain squalls.
8	12 55 N.	149 13	191	Moderate breeze from E. by S. to ESE. Clear to cloudy, with light rain squalls.
9	13 10 N.	147 12	119	Gentle breeze from NE. to E. by S. Clear.
10	13 19 N.	145 10	119	Gentle breezes from SE. to E. Clear. 7h 30m a. m. Guam sighted ahead.
11	Guam	....	30	3 p. m. made fast to mooring-buoy in harbor of Port Apra, Guam.

Total distance, 1,550 miles. Time of passage, 11.3 days. Average day's run, 137.2 miles.

GUAM TO YOKOHAMA.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1906	° ′	° ′	*miles*	
July 24	Guam	....	....	11h 20m a. m., left mooring-buoy in harbor of Apra, Guam. Calm to light breezes from ENE. Cloudy to clear.
25	15 36 N.	144 20	131	Moderate breezes from E. by N. to E. by S. Long, rolling swells. Clear.
26	17 45 N.	144 15	129	Calm to gentle breezes from E. Cloudy.
27	18 45 N.	144 12	60	Calm to gentle breezes from E. to NE. Partly cloudy to overcast.
28	19 31 N.	144 18	46	Calm to gentle breezes from NE. to E. Partly cloudy.
29	20 13 N.	144 15	42	Light to gentle breezes from SE. to E. by S. Clear to cloudy, with wind squalls.
30	21 29 N.	144 43	80	Gentle breezes from NW. to SW. and calm. Overcast, with light rains to partly cloudy.
31	21 54 N.	144 49	26	Light to moderate breeze from SE. to W. by S. Cloudy, with light rains and squalls.
Aug. 1	24 28 N.	145 23	157	Moderate to stiff breeze from SW. Rough sea. Partly cloudy to overcast, with rain squalls.
2	27 42 N.	145 29	194	Moderate to stiff breeze from SW. Overcast, with rain and squalls.
3	29 33 N.	144 44	118	Moderate breeze from NW. to WNW. Partly cloudy to clear. Swung ship p. m.
4	30 39 N.	144 36	66	Gentle to moderate breeze from SW. to W. Light rain squall. Rough sea. Partly cloudy.
5	29 58 N.	144 12	46	Calm to moderate breezes from WNW. to W. by S. Light rains and squalls. Cloudy to clear.
6	30 36 N.	144 07	38	Calm to gentle breezes from N. by E. Clear.
7	31 07 N.	142 26	92	Stiff to light breezes from N. to N. by W. Clear. Swung ship p. m.
8	31 44 N.	141 21	67	Light breezes from SW. to WSW. Clear to overcast.
9	31 58 N.	140 58	24	Gentle breezes from NE. and calm. Clear to cloudy.
10	33 44 N.	138 56	147	Fresh breeze from NE. Rough sea. Cloudy. 4h 30m a.m. Fatsizio Island sighted.
11	34 09 N.	139 42	46	Stiff breeze from NE., followed by light airs from E. by S. Partly cloudy.
12	34 54 N.	139 42	45	Light breezes from NE. to SE. Cloudy to clear.
13	Yokohama	....	33	1h 20m a. m. anchored in Yokohama Bay.

Total distance, 1,587 miles. Time of passage, 19.6 days. Average day's run, 81.0 miles.

YOKOHAMA TO SAN DIEGO.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1906	° ′	° ′	*miles*	
Sept. 6	Yokohama	....	....	Left Yokohama, 10h 30m a. m. Swung ship by tug. Light airs. Overcast and drizzling p. m.
7	34 47 N.	139 46	40	Light variable breezes. Cloudy, followed by overcast and rain.
8	35 35 N.	143 15	178	Stiff breezes N. by W. to NNE. Clear. Ship pitching and rolling.
9	35 34 N.	144 47	75	Light SE. breezes. Rain in evening.
10	35 35 N.	147 50	149	Moderate breezes. Clear to partly cloudy. Swung ship on 5 headings, port and starboard.
11	36 36 N.	150 57	163	Gentle breezes from N. to NE. Cloudy.
12	35 37 N.	151 19	61	Stiff breezes, diminishing, from NE. Cloudy.
13	37 53 N.	150 02	149	Stiff ESE. to ENE. breezes. Overcast. Pitching and plunging.
14	41 06 N.	149 46	193	Fresh breezes from E. Cloudy. Too rough for work.
15	43 14 N.	149 38	128	Gentle E. to SE. breezes. Clear to overcast p. m. Swung ship on 6 headings, both helms.

YOKOHAMA TO SAN DIEGO—*concluded.*

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1906	° ′	° ′	*miles*	
Sept. 16	44 26 N.	152 05	128	Gentle breeze from S., increasing to moderate gale. Long swells. Clear to overcast.
17	45 32 N.	155 45	169	Gale from S., diminishing to gentle breeze SW. at noon. Overcast, drizzling to partly cloudy. Too rough for work.
18	45 19 N.	158 35	120	Moderate to SW. breeze. Cloudy, drizzling. Ship rolling.
19	46 05 N.	161 23	126	Light breeze SW. to WNW. Cloudy with mist p. m. Continuous rolling.
20	45 31 N.	162 37	62	Gale from NE. Hove to. Overcast, with rain.
21	44 54 N.	164 58	106	Fresh NW. breeze. Cloudy.
22	44 57 N.	167 44	118	Gentle breeze NW. to N. by E. Cloudy. Swung ship both helms. Declination on one heading.
23	44 19 N.	170 52	139	Stiff breeze from NE. Overcast and cloudy.
24	41 47 N.	173 35	193	Stiff breeze from ENE. Cloudy and drizzling.
25	42 56 N.	174 11	74	Gentle breeze varying SE. to ENE. Cloudy.
26	43 34 N.	174 56	50	Light airs, various, to calm. Clear fine day. Swung ship on 6 headings, both helms.
27	44 07 N.	176 19	69	Moderate breeze S., freshening p. m. Cloudy to overcast, with rain.
27	44 57 N.	181 28	226	Stiff breeze, freshening from NW. Clear. Yawing and pitching. Crossed 180th meridian. Changed date at 4^h 30^m a. m.
28	45 39 N.	187 08	243	Fresh breeze from W. Overcast and drizzling. Tremendous following sea.
29	45 59 N.	192 20	218	Fresh W. to NW. breeze, diminishing. Clear a. m. to overcast p. m.
30	45 34 N.	195 13	123	Moderate breeze N. Clear. Swung ship p. m., 6 points, both helms.
Oct. 1	45 17 N.	198 55	157	Moderate NW. breeze. Clear. Ship yawing considerably.
2	45 57 N.	200 16	69	Light breeze from E. by N., increasing to NE. gale. Overcast, with rain. Hove to at 8 p. m. Gale from N. by W. moderating. Sea rough.
3	45 27 N.	201 19	53	Overcast, with drizzle. Hove to.
4	44 10 N.	203 58	137	Strong northeasterly winds. Rough sea, squally. Clear a. m. Overcast, with drizzle, p. m.
5	42 34 N.	206 34	149	Light northerly breeze, with fog and driving mist. Calm p. m.
6	42 57 N.	209 36	136	Stiff southerly breeze. Rain and fog all day.
7	43 37 N.	214 17	208	Stiff breeze from S., shifting SE. Overcast, with rain.
8	44 36 N.	217 07	136	Gale from S. during night. Hove to. Rain-storm from SW. Cleared p. m.
9	43 29 N.	220 03	143	Stiff breeze, SW. shifting to S. by E. Clear.
10	43 01 N.	225 15	229	Stiff southerly breeze, increasing to gale a. m. Abated somewhat p. m. Cloudy and rainy. Rough sea.
11	41 04 N.	228 36	190	Stiff SW. breeze shifting to W. Heavy sea. Clear.
12	39 48 N.	230 42	122	Light breeze from SW. Cloudy. Swung ship on 5 headings, both helms.
13	38 59 N.	232 01	78	Light variable westerly winds. Cloudy, becoming foggy.
14	37 11 N.	234 55	174	Light NW. breeze. Clear.
15	35 26 N.	237 34	166	Stiff NW. breeze. Clear. Ship rolling considerably. Swung ship a. m., 6 headings, both helms.
16	33 10 N.	240 38	204	Moderate NW. breeze, diminishing. Moderate sea. Sighted San Nicholas. Clear.
17	33 12 N.	241 21	36	Becalmed off Santa Catalina during night. Light head-wind a. m. Calm p. m. Clear.
18	33 10 N.	241 44	19	Calm and various light airs. Tacking between Santa Catalina and San Clemente. Overcast.
19	33 00 N.	242 23	34	Calm and light airs. NW. breeze p. m. Partly cloudy. Anchored off bell-buoy, unable to sail in.
20	San Diego.	....	29	Under tow of tug boat. Dropped anchor off Santa Fe dock, San Diego, at 11 a. m.

Total distance, 5,769 miles. Time of passage, 45 days. Average day's run, 128.2 miles.

Summary of Passages for Cruise II of the Galilee.

TABLE 43.

Passage	Length of passage	Time of passage	Average day's run
	miles	*days*	*miles*
San Diego to Fanning Island......	3,172	28.1	113
Fanning Island to Apia..........	1,502	15.4	98
Apia to Suva....................	682	6.1	112
Suva to Jaluit..................	2,024	26.1	78
Jaluit to Guam..................	1,550	11.3	137
Guam to Yokohama...............	1,587	19.6	81
Yokohama to San Diego.........	5,769	45.0	128
Total....................	16,286	151.6	107

W. J. PETERS: ABSTRACT OF LOG, CRUISE III, 1906–1908.[1]

SAN DIEGO TO NUKAHIVA, MARQUESAS ISLANDS.

Date	Noon position Lat.	Long. E. of Gr.	Day's run	Remarks
1906	° ′	° ′	*miles*	
Dec. 22	San Diego.			Under way with tug at 3^h 15^m p. m. Cast off with sails all set at 4^h 30^m p. m.
23	32 04 N.	241 53	57	Gentle NW. breeze. Clear.
24	30 28 N.	240 44	113	Light breeze N. by E. to NW. Clear, becoming overcast. Christmas-eve festivities aboard.
25	29 23 N.	240 14	70	Calm to gentle breeze, variable SE. to SSW. Overcast. Guadalupe Island bearing E. at 8 a. m.
26	28 38 N.	240 31	47	Gentle breeze variable SSE. to SW. by S. Overcast and damp.
27	28 17 N.	240 02	33	Variable winds. Squally, with continuous rain. Swell from W.
28	27 31 N.	238 59	72	Heavy squalls, cleared in a. m. with gentle NW. winds. Swung ship p. m.
29	25 29 N.	238 31	125	Gentle NW. breeze, becoming NNE. Clear. Ship rolled heavily, wind being dead aft.
30	23 11 N.	237 34	147	Gentle NE. winds. Cloudy, becoming clear.
31	21 17 N.	236 55	120	Light NW. breeze increasing to NNE. Cloudy, becoming clear. Swung ship on 7 headings, both helms.
1907				
Jan 1	18 39 N.	236 12	163	Stiff NE. breeze. Clouds, squalls. Ship rolling and yawing in following sea.
2	14 47 N.	235 02	241	NE. winds becoming boisterous. Partly cloudy. Heavy seas keep decks wet. Yawing widely.
3	10 41 N.	233 37	260	Fresh NE. winds. Partly cloudy. Unfavorable conditions continue. Westerly drift noticeable.
4	9 00 N.	232 41	115	Calm, and variable light airs. Rain, squalls, clouds. Heavy sea running.
5	8 51 N.	233 22	41	Calm, with light variable airs. Overcast, with rain. Squally. Heavy sea and ship rolling.
6	8 34 N.	235 21	119	Calm, no steerage-way. Partly cloudy. Large drift to eastward.
7	7 27 N.	235 16	67	Very light northerly winds. Partly cloudy, with passing showers.
8	6 17 N.	234 41	78	Calm to moderate SE. breeze. Partly cloudy. Swung ship. Sea fairly smooth.
9	4 52 N.	232 56	135	Gentle SSE. breeze. Partly cloudy, becoming squally.
10	4 12 N.	231 53	74	Light breeze from ESE. Partly cloudy to clear. Moderate roll. Heavy set to NW.
11	3 23 N.	230 39	88	Light breeze from ESE. Cloudy and partly cloudy. Attempted swing, but wind failed. Heavy roll.
12	2 08 N.	229 45	92	Gentle breeze ESE. Partly cloudy. Swung ship. Sea fairly smooth, moderate swell.
13	1 31 N.	228 59	59	Gentle breeze from ESE. to SE. Clear.
14	0 25 S.	228 04	165	Fresh breeze from E. by S. Clear. Ship pitching. Crossed equator at 9 a. m.
15	3 31 S.	227 02	196	Moderate breeze E. by S. to E. by N. Partly cloudy. Swung ship. Sea moderate. Crossed magnetic equator.
16	6 14 S.	224 52	208	Fresh breeze, ESE. to ENE. Partly cloudy. Heavy sea, ship rolling and yawing.
17	7 59 S.	222 06	195	Fresh breeze, ENE. to NE. Partly cloudy. Ship yawing and rolling heavily.
18	Nukahiva.		140	Anchored inside harbor, Nukahiva, Marquesas Islands, at 8^h 45^m a. m.

Total distance, 3,220 miles. Time of passage, 26.7 days. Average day's run, 120.6 miles.

NUKAHIVA, MARQUESAS ISLANDS, TO TAHITI, SOCIETY ISLANDS.

Date	Lat.	Long.	Day's run	Remarks
1907	° ′	° ′	*miles*	
Jan. 24	Nukahiva.			9^h 30^m a. m., left anchorage. Light variable airs. Partly cloudy.
25	9 25 S.	219 04	60	Light variable airs and calm. Partly cloudy.
26	10 16 S.	217 47	91	Light airs from NE. Light rain at 12^h 30^m p. m. Partly cloudy.
27	11 31 S.	216 06	124	Gentle breeze from ENE. Partly cloudy.
28	12 59 S.	214 00	151	Gentle breeze from ENE. Partly cloudy. Overcast, with rain, p. m.
29	14 16 S.	212 33	114	Light airs from NE. Partly cloudy a. m. Overcast, with rain, p. m.
30	15 15 S.	211 24	89	Gentle breezes from E. to ESE. Partly cloudy. Smooth sea, best conditions.
31	Tahiti		143	3^h 45^m p. m. anchored in Papeete Harbor. Light ESE. breezes. Partly cloudy.

Total distance, 772 miles. Time of passage, 7.3 days. Average day's run, 105.8 miles.

[1]For synopsis of this cruise, see pages 12-14.

TAHITI, SOCIETY ISLANDS, TO APIA, SAMOAN ISLANDS.

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1907	° ′	° ′	*miles*	
Feb. 19	Tahiti....	....	......	$10^h 30^m$ a. m. left Papeete Harbor. Gentle N. by E. breeze. Partly cloudy.
20	17 06 S.	206 54	208	Moderate northerly breeze. Rough sea. Heavy W. swell. Partly cloudy.
21	16 58 S.	203 20	205	Gentle breeze from N. Overcast, with heavy squalls and passing showers. Ship tossing heavy.
22	17 03 S.	201 19	116	Moderate N. breeze., next calm. Bad weather, squalls and heavy seas.
23	17 30 S.	199 29	108	Calm, variable breezes. Light rains. Partly cloudy.
24	18 01 S.	199 03	40	Calm. Partly cloudy. Unable to hold heading.
25	17 38 S.	197 54	69	Light SE breeze, shifting to ESE., partly cloudy, sea smooth. Mod. swell.
26	16 40 S.	195 49	133	Light breeze from E. by S. to E. Partly cloudy. Swung ship. Sea smooth.
27	16 18 S.	194 09	98	Gentle breeze from E. and light airs from WNW. Sea moderate. Unable to hold steady heading.
28	15 50 S.	193 34	44	Light variable airs. Rain. Partly cloudy. Ship holding no definite heading.
Mar. 1	15 21 S.	191 51	103	Gentle ESE. breeze. Partly cloudy to overcast. Rolling and yawing badly.
2	14 35 S.	189 58	118	Light easterly breeze. Considerable magnetic change while passing Tutuila.
3	Apia......	....	110	$1^h 30^m$ p. m., anchored in Apia Harbor. Overcast, with light rains.

Total distance, 1,352 miles. Time of passage, 12.1 days. Average day's run, 111.7 miles.

APIA, SAMOAN ISLANDS, TO YAP, CAROLINE ISLANDS.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1907	° ′	° ′	*miles*	
Mar. 14	Apia......	....	......	Left $8^h 10^m$ a. m. Gentle E. breeze, shifting to ESE. Cloudy, passing showers.
15	10 45 S.	187 07	196	Gentle breeze from SE. to ESE. Rough sea. Overcast, squalls, light rains.
16	8 59 S.	185 14	154	Light breezes from ESE. to ENE. Partly cloudy. Considerable southerly set.
17	7 28 S.	183 00	161	Light variable wind. Overcast, with light rains.
18	7 15 S.	181 02	118	Calm. Heavy squalls. Overcast, with heavy rain, to partly cloudy.
20	6 37 S.	179 04	123	Moderate NNE. breeze. Ship swung. Crossed 180th mer. Partly cloudy.
21	5 22 S.	176 36	165	Moderate breeze from NNE. Rough sea. Partly cloudy. Ship swung.
22	3 34 S.	173 22	222	Moderate NE. breeze. Partly cloudy to overcast, heavy rains and squalls.
23	2 34 S.	170 32	180	Gentle breeze from NE. Partly cloudy. Ship rolling and pitching.
24	1 08 S.	167 29	202	Moderate breeze from ENE. Partly cloudy, heavy squalls, rain, thunder.
25	0 02 S.	165 40	127	Variable winds, squalls, rough sea, overcast, heavy rain. Crossed equator.
26	1 03 N.	163 52	126	Gentle breeze from ESE. Partly cloudy. Considerable sea.
27	2 25 N.	161 47	149	Light ENE. breeze. Overcast, with light rains to partly cloudy. Ship swung.
28	2 40 N.	161 22	29	Variable breezes. Partly cloudy, with heavy squalls.
29	2 52 N.	160 29	54	Mod. NW. breeze shifting to NNW. Overcast, heavy squalls, rain.
30	3 05 N.	159 36	54	Light breeze from NNE. Partly cloudy.
31	3 19 N.	157 53	104	Light breeze from NNE. shifting to NE. and increasing. Overcast, with rain and squalls, to partly cloudy. Ship swung on 6 headings.
Apr. 1	3 48 N.	155 32	144	Gentle breeze from NE. Partly cloudy.
2	4 29 N.	153 15	144	Light breeze from NE. Partly cloudy. Weather fine.
3	5 16 N.	150 52	150	Mod. breeze from N. by E. shifting to NNE. Partly cloudy. Ship swung.
4	5 54 N.	149 43	78	Light airs from NNE. to calm. Partly cloudy.
5	6 18 N.	149 39	24	Calm and partly cloudy.
6	6 37 N.	149 51	22	Calm and partly cloudy. Ship swung on all but E. heading of port helm.
7	6 36 N.	149 10	41	Variable winds. Partly cloudy. A. M. passed Suk I. 5 natives came out in canoe.
8	6 50 N.	147 18	112	Gentle breeze from ESE. Partly cloudy.
9	7 02 N.	145 56	83	Light easterly breezes. Partly cloudy.
10	7 37 N.	144 05	116	Gentle breeze from NE. Clear. Ship swung on 7 headings, both helms.
11	7 55 N.	142 30	96	Light airs from NE. Clear.
12	8 34 N.	140 46	110	Gentle breeze from NE. Partly cloudy.
13	9 08 N.	138 55	115	Gentle breeze from ENE. Partly cloudy. Sighted Yap about $4^h 30^m$ p. m.
14	Yap......	....	55	10 a. m. anchored in Tomil Bay, Yap.

Total distance, 3,454 miles. Time of passage, 30.1 days. Average day's run, 114.8 miles.

YAP, CAROLINE ISLANDS, TO SHANGHAI.

Total distance, 1,734 miles. Time of passage, 15.1 days. Average day's run, 114.9 miles.

SHANGHAI TO SITKA.

Total distance, 5,507 miles. Time of passage, 41.2 days. Average day's run, 133.7 miles.

SITKA TO HONOLULU.

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1907	° ′	° ′	*miles*	
Aug. 10	Sitka			5 a. m., left anchorage at Sitka. Partly cloudy.
11	55 31 N.	221 41	136	Calm. Foggy, with rain, to partly cloudy.
12	55 42 N.	221 07	22	Calm. Partly cloudy.
13	54 10 N.	220 16	96	Light westerly breeze. Partly cloudy. Ship swung on 7 headings, starboard.
14	52 50 N.	221 15	87	Moderate breeze from SW. Overcast and hazy. Rough sea.
15	49 14 N.	222 03	218	Moderate breeze from SW. Overcast and hazy.
16	45 56 N.	222 52	200	Moderate westerly breezes. Overcast and misty. Ship swung on 6 headings.
17	43 38 N.	222 47	138	Light breeze from N. Partly cloudy.
18	41 41 N.	222 48	117	Light northerly breezes. Partly cloudy.
19	39 50 N.	222 38	111	Light breeze from NE. Ship swung p. m.
20	37 25 N.	222 27	146	Gentle breeze from NE. Cloudy.
21	35 23 N.	220 00	170	Light breeze from NE. Partly cloudy.
22	33 25 N.	217 28	172	Light breeze from NNE. Partly cloudy.
23	31 57 N.	215 34	130	Light variable airs. Clear to cloudy.
24	30 56 N.	214 10	94	Moderate breeze from ENE. Partly cloudy. Ship swung a. m.
25	28 50 N.	211 43	179	Gentle easterly breezes. Cloudy to clear.
26	26 10 N.	208 42	227	Stiff breeze from ENE. Partly cloudy to overcast, with passing showers.
27	22 55 N.	204 28	303	Stiff breeze from E. Rough sea. Clear.
28	Honolulu		162	1^h^ 30^m^ p. m., anchored outside harbor of Honolulu.

Total distance, 2,708 miles. Time of passage, 18.3 days. Average day's run, 148.0 miles.

HONOLULU TO JALUIT, MARSHALL ISLANDS.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1907	° ′	° ′	*miles*	
Sept. 26	Honolulu			2 p. m. tug came. All sails set at 3 p. m., light NE. breeze. Partly clear.
27	21 44 N.	199 43	137	Light E. breeze. Partly cloudy. Swung ship p. m. near Kaula I. Sea rough.
28	22 43 N.	196 59	164	Gentle breeze, NE. and ENE. Partly cloudy, with passing showers at evening. Moderate sea.
29	23 25 N.	193 55	175	Gentle breeze, ENE. Partly cloudy.
30	24 06 N.	191 28	141	Light breeze from E. Weather squally.
Oct. 1	24 41 N.	189 58	89	Calm and squally weather. Sea smooth.
2	24 50 N.	189 24	32	Calm a. m. Good breeze from N. about noon. Squally. Sea rough and ship pitching heavily.
3	26 21 N.	185 50	213	Moderate breeze N. by W. to NE. Partly cloudy. Sea rough. Ship rolling and yawing.
4	27 54 N.	183 17	165	Gentle breeze, ENE. Partly cloudy. Sighted Midway about 5 p. m., too late to make anchorage. Tacked until morning.
5	Midway Islands		39	Cast anchor in Seward Roads, Midway at 10 a. m. Surf too heavy to make landing from launch. Cable company's party took lunch aboard. Heaved anchor at 5 p. m. and sailed for Jaluit. Light NE. breeze. Partly cloudy.
6	26 39 N.	181 31	111	Light breeze from ENE. Clear.
7-8	23 47 N.	179 43	198	Gentle NE. breeze. Partly cloudy. Crossed 180th meridian about 9 a.m. Swung ship p. m. Sea moderate.
9	21 18 N.	178 08	173	Stiff NE. by E. to E. breeze. Partly cloudy. Sea rough. Rolling and pitching.
10	17 56 N.	176 18	227	Stiff E. breeze. Partly cloudy. Sea rough. Rolling, pitching, yawing.
11	14 41 N.	174 16	228	Moderate E. wind. Cloudy. Sea rough.
12	12 17 N.	172 26	179	Light E. breezes. Cloudy, with passing showers. Swung ship in morning.
13	9 30 N.	171 27	177	Light airs, mostly easterly. Showery.
14	8 54 N.	170 46	54	Calm. Cloudy.
15	8 18 N.	170 28	31	Calm. Cloudy, showery. Generally overcast.
16	7 53 N.	170 44	30	Calm. Squally weather. Sighted two small islands bearing NE. at 8 a. m.
17	7 20 N.	170 26	38	Calm, rainy, squally weather.
18	6 47 N.	170 10	37	Calm. Cloudy.
19	6 25 N.	170 31	30	Calm and light airs. Sighted land at 6 p. m. Tacked ship until morning.
20	5 55 N.	169 39	60	Tacked all day to make entrance to Jaluit Harbor. Light breeze dead ahead.
21	Jaluit			Beating in, waiting for tide. Dropped anchor at 11^h^ 30^m^ a. m. at Jaluit.

Total distance, 2,728 miles. Time of passage, 23.8 days. Average day's run, 114.6 miles.

JALUIT, MARSHALL ISLANDS, TO PORT LYTTELTON, NEW ZEALAND.

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1907	° ′	° ′	*miles*	
Nov. 11	Jaluit......	....	....	At 1 p. m. steamer *Titus* secured to tow ship out of lagoon, where she had lain at anchor since Nov. 5, waiting for a favorable wind.
12	3 47 N.	170 00	130	Calm and light easterly airs. Cloudy, with squalls in evening.
13	2 13 N.	169 00	111	Calm and light airs from ESE. Partly cloudy.
14	0 26 N.	168 34	110	Light easterly breezes. Generally clear. Swung ship. Crossed equator about 5 p. m.
15	2 06 S.	169 00	154	Calm and gentle easterly breezes. Clear.
16	5 00 S.	169 31	177	Breezes from ENE. to E. Partly cloudy.
17	6 41 S.	169 19	102	Light breezes, SE. Generally clear.
18	7 35 S.	169 05	56	After a swing for declination in morning the wind failed. Clear.
19	7 31 S.	169 16	11	Calm. Clouds, clearing later.
20	7 40 S.	170 13	57	Calm. Partly cloudy.
21	7 57 S.	170 06	18	Calm. Few clouds. Sea smooth.
22	9 33 S.	169 24	105	Light breeze from E. Slightly cloudy. Swung ship both helms.
23	11 21 S.	168 49	113	Gentle ESE. breeze. Partly cloudy.
24	13 12 S.	167 48	126	Moderate ESE. breeze, diminishing. Partly cloudy.
25	13 21 S.	168 09	22	Calm. Cloudy, squalls and rain p. m.
26	13 47 S.	168 24	30	Light breeze from ESE. Squally.
27	14 55 S.	168 13	69	Calm and squalls.
28	15 25 S.	168 26	32	Calm and light airs from ESE. Cloudy.
29	16 02 S.	168 38	39	Gentle breeze ESE. Tacking ship and beating up against wind to clear New Hebrides Islands.
30	16 44 S.	168 57	46	Moderate E. breeze. Squally. Sailing close to wind to clear New Hebrides Islands.
Dec. 1	18 12 S.	168 57	88	Moderate wind E. by S. Generally cloudy.
2	20 53 S.	169 22	163	Light breezes generally SE. Heavy squall p. m. Overcast and rain.
3	21 14 S.	169 58	40	Calm. Partly cloudy.
4	21 21 S.	171 13	70	Light airs and calm. Cloudy a. m., clearing. Sea smooth.
5	21 38 S.	170 51	39	Calm. Clear.
6	22 05 S.	170 44	28	Calm. Clear.
7	22 40 S.	170 36	36	Calm. Partly cloudy.
8	23 25 S.	170 29	45	Light airs from E. and ESE. Sea smooth. Crossed tropic of Capricorn this p. m.
9	25 12 S.	169 52	112	Light breeze from ESE. to E. Mostly clear. Swung ship p. m.
10	27 43 S.	170 15	152	Light airs, E. by N. to NE. Partly cloudy.
11	29 30 S.	170 24	107	Light airs NE. to NNW. Partly cloudy.
12	30 21 S.	170 40	53	Light breeze from S. to SSE. Cloudy, partly clearing p. m.
13	30 50 S.	172 00	75	Light breeze from SSE. to S. by W. Clear. Sea smooth.
14	31 23 S.	171 16	50	Calm. Clear.
15	32 35 S.	170 56	74	Light airs from E. by S. to SE. Clear.
16	34 21 S.	170 28	108	Light breeze, E. by S. Clear.
17	36 09 S.	170 07	109	Light breeze from SE. Cloudy.
18	37 30 S.	170 09	81	Light airs from NE. Cloudy, overcast p. m.
19	39 00 S.	172 38	148	Moderate breeze from NNE. to NW. Overcast and threatening, with falling barometer.
20	40 35 S.	173 38	105	Strong SE. breeze, shifting from ESE. to SSE. Tacking, trying to beat through Cook Strait against head-wind.
21	40 45 S.	174 38	47	Beating through Cook Strait against head-wind.
22	41 16 S.	174 35	31	Beating through Cook Strait against wind and tide.
23	42 40 S.	174 06	87	Gentle N. breeze. Cloudy. Sailing along coast of South Island, New Zealand.
24	Port Lyttelton......		80	Moored alongside breakwater in Port Lyttelton Harbor at 4 p. m.

Total distance, 3,436 miles. Time of passage, 43.1 days. Average day's run, 79.7 miles.

PORT LYTTELTON TO CALLAO.

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1908	° ′	° ′	*miles*	
Jan. 17	Lyttelton	....	......	9h 30m a. m. left Port Lyttelton under tow, from breakwater and halfway down channel. Sailed out with good SW. breeze.
18	43 20 S.	177 37	209	Moderate S. wind. Squally. Sea rough. Showers. Ship yawing.
18	43 01 S.	180 13	116	Calm. Partly cloudy. Crossed 180th meridian about 1 a. m.
19	42 45 S.	182 03	82	Light SW. breeze, increasing. Partly cloudy.
20	42 46 S.	186 48	209	Stiff wind from NNW. Squally. Tackle on main boom gave away, with damage to boom. Starboard log carried away.
21	42 08 S.	192 32	257	Fresh S. breeze. Partly cloudy. Rough sea.
22	41 42 S.	196 23	174	Moderate NW. breeze. Overcast. Ship rolling and yawing badly.
23	41 36 S.	200 57	205	Moderate NW. breeze. Overcast and drizzling. Sea rough.
24	42 12 S.	205 39	213	Gentle NW. breeze. Mostly clear.
25	42 04 S.	208 21	120	Calm. Partly cloudy.
26	42 02 S.	209 26	48	Calm. Overcast and foggy.
27	42 51 S.	211 22	99	Light N. by E. breeze. Overcast and foggy. Swung ship both helms.
28	43 13 S.	213 18	88	Light variable airs, to gentle SSE. breeze. Overcast.
29	42 36 S.	217 46	200	Moderate gale, abating, from SSE. Overcast and threatening. Sea rough; p. m. partly cloudy.
30	42 20 S.	222 28	209	Moderate S. to SSW. breeze. Overcast.
31	42 07 S.	224 31	92	Calm. Overcast. Attempt to swing by launch abandoned on account of heavy swell.
Feb. 1	42 08 S.	224 47	12	Calm. Overcast.
2	42 29 S.	225 37	43	Calm. Overcast, breaking at sunset.
3	43 17 S.	226 48	71	Calm a. m. Moderate NE. breeze later. Overcast and hazy.
4	45 07 S.	227 58	121	Light breeze from E. Overcast and hazy.
5	44 43 S.	229 32	71	Gentle breeze SE. to S. by W. Partly cloudy. Swung ship.
6	44 09 S.	232 16	122	Light breeze, increasing SW. to N. by W. Partly cloudy.
7	43 22 S.	237 03	212	Stiff to fresh northerly wind. Sea rough. Overcast. Barometer falling and wind rising.
8	43 12 S.	241 48	208	Barometer continued to fall steadily. Heavy gale at 3 a. m. from NNW. At 5 p. m. lower topsail carried away. Gale continued to midnight. Scudding before wind at 10 knots under bare poles.
9	42 12 S.	246 11	202	Gale abated somewhat at 4 a. m. Partly cloudy. Mountainous seas throughout day.
10	41 11 S.	248 42	128	Gentle NW. breeze. Overcast. Long swells. Ship rolling and yawing.
11	41 09 S.	252 13	160	Storm from NNW. All sails made fast, except storm staysail. Abated about 10 a. m. Overcast. Choppy sea.
12	38 48 S.	253 46	158	Gentle SW. breeze. Overcast and squally.
13	36 58 S.	255 30	137	Light breeze SE. to ENE. Overcast, breaking p. m.
14	36 26 S.	256 18	50	Gentle northerly breezes to calm. Overcast, breaking at nightfall.
15	37 09 S.	257 54	88	Light northeasterly breezes. Mostly overcast.
16	37 39 S.	259 19	74	Calm. Partly cloudy.
17	36 55 S.	259 05	45	Light E. to NE. breezes. Partly cloudy. Swung ship at sunrise for declination. Swung later for intensity.
18	36 46 S.	259 10	10	Calm. Cloudy.
19	35 14 S.	261 08	133	Light airs WNW. Partly cloudy.
20	34 06 S.	262 40	102	Light airs WNW. Partly cloudy.
21	33 38 S.	263 49	64	Light airs northwesterly. Partly cloudy.
22	33 06 S.	264 53	62	Calm. Partly cloudy.
23	32 38 S.	265 21	37	Light airs S. and SE. Partly cloudy.
24	31 03 S.	266 39	116	Light breezes SE. to NNE. Partly cloudy.
25	28 39 S.	267 59	160	Stiff breeze E. by N. Squally. Rough sea. Ship yawing badly.
26	26 51 S.	268 00	108	Light NE. breeze. Overcast and squally.
27	25 56 S.	268 19	58	Gentle easterly breezes. Overcast and squally.
28	24 29 S.	268 42	89	Shifting winds WNW. to E. Could not hold heading long enough for observations. Mostly overcast.
29	22 26 S.	269 54	140	Gentle breezes ESE. to E. Overcast, breaking towards evening, permitting observations.
Mar. 1	20 37 S.	271 11	130	Gentle breezes from E. by S. Overcast, with squalls a. m.
2	19 14 S.	272 15	102	Calm. Overcast and squally.
3	18 51 S.	272 56	45	Calm. Cloudy.
4	18 36 S.	273 52	55	Light airs from SE. by E. Cloudy.
5	18 05 S.	275 26	94	Light airs, mostly SE. Partly cloudy. Sea smooth.
6	17 22 S.	277 02	101	Light airs from ESE. Partly cloudy. Swung ship at sunrise for declination, later for intensity, both helms.
7	16 16 S.	278 35	111	Light airs from ESE. Overcast.
8	15 13 S.	280 03	105	Light airs generally ESE. Partly cloudy.
9	13 48 S.	282 12	151	Moderate breeze ESE. and E. by S. Partly cloudy.
10	Callao....	....	105	Sighted land at dawn. Sailed in with light winds. Dropped anchor in Callao Harbor at 4h 30m p. m.

Total distance, 6,301 miles. Time of passage, 54.3 days. Average day's run, 116.0 miles.

CALLAO TO SAN FRANCISCO.

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1908	° ′	° ′	*miles*	
Apr. 5	Callao....	....	......	Set sail 5 p. m., Callao for San Francisco. Light airs from S.
6	11 39 S.	282 17	40	Light to gentle breeze from SE. Overcast, partly clearing.
7	11 18 S.	280 20	117	Gentle breeze SE. Partly cloudy.
8	10 22 S.	277 50	158	Light SE. breeze. Clear, clouding p. m.
9	9 39 S.	275 15	159	Moderate SE. breeze. Overcast, breaking away. Swung ship p. m. both helms.
10	8 57 S.	272 34	164	Gentle SE. breeze. Clouds. Sea moderate.
11	8 12 S.	269 52	166	Moderate breeze from SE. Overcast. Sea moderate.
12	7 36 S.	267 24	151	Moderate SE. breeze. Overcast. Sea moderate.
13	6 39 S.	264 02	205	Moderate, ESE. breeze. Overcast. Sea moderate. Swung ship both helms.
14	5 47 S.	260 43	202	Gentle breeze from SE. Partly cloudy. Sea moderate.
15	5 15 S.	257 58	167	Moderate breeze E. by S. and SE. Partly cloudy. Overcast and squalls early p. m.
16	4 57 S.	255 33	146	Gentle breeze ESE. to SE. Partly cloudy.
17	4 28 S.	253 05	150	Gentle breeze E. by S. to SE. Overcast, breaking away and squalls p. m. Swung ship on 6 headings, port helm, and on 5, starboard helm.
18	3 49 S.	251 27	105	Light SE. breeze. Overcast, with passing showers. Sea smooth.
19	2 50 S.	249 09	150	Light breeze SE. Overcast and squally.
20	1 46 S.	247 16	130	Light breeze SE. Overcast. Sea smooth.
21	1 03 S.	246 02	86	Light airs, variable. Overcast, with squalls. Sea smooth.
22	0 19 N.	246 41	91	Calm with light airs NE. p. m. Generally cloudy. Crossed equator about 7 a. m.
23	2 06 N.	246 31	107	Gentle breeze ENE. to ESE. Generally cloudy. Moderate sea.
24	4 33 N.	246 11	148	Gentle breezes from E. to S. Generally cloudy, with squalls and heavy rains.
25	6 14 N.	246 11	101	Gentle breezes SE. to SW. Mostly overcast, with squalls of heavy rain.
26	7 51 N.	246 08	97	Calm and light S. to SW. breezes. Mostly overcast, with squalls.
27	8 29 N.	246 06	38	Light airs from NE. to NW. Squalls and rain at intervals through day.
28	9 33 N.	245 59	64	Light airs from W. to S. Squally weather. Smooth sea.
29	10 30 N.	246 04	57	Calm and light airs from S. and SW. Rain, squalls, and generally overcast. Smooth sea.
30	11 44 N.	246 11	74	Calm, not wind enough for steering. Overcast, breaking somewhat. NE. breeze in evening. Sea smooth.
May 1	12 53 N.	245 35	77	NE. trades, gentle, with occasional squalls. Sea moderate.
2	13 50 N.	243 51	116	NE. trades, moderate. Mostly overcast. Sea smooth.
3	15 06 N.	242 23	114	Moderate breeze NNE. Cloudy, with occasional breaks. Moderate sea.
4	16 28 N.	240 19	145	Moderate breeze from NNE. to N. Overcast all day. Swung ship, both helms.
5	17 43 N.	238 23	134	Moderate breeze NE. to N. Partly cloudy. Moderate sea.
6	18 33 N.	236 27	121	Light airs from N. Overcast.
7	20 10 N.	233 43	183	Moderate breeze from NNE. Sky overcast. Ship driving into a heavy sea.
8	22 27 N.	231 54	171	Stiff NE. breeze. Overcast and threatening. Sea rough.
9	24 34 N.	229 42	175	Stiff breeze from NNE., diminishing slightly. Sky overcast and sea rough.
10	26 26 N.	228 06	142	Moderate breeze from NNE. Moderate sea. Cloudy weather continues.
11	27 54 N.	226 09	136	Gentle NNE. breeze. Cloudy weather continues.
12	29 20 N.	224 36	119	Light NNE. breeze. Overcast all day. Sea smooth.
13	30 12 N.	223 49	66	Light airs. Overcast, breaking toward evening. Sea smooth.
14	30 24 N.	223 28	22	Calm. Mostly overcast.
15	30 52 N.	222 40	50	Calm. Mostly overcast.
16	31 12 N.	222 38	20	Calm. Gentle SSW. breeze p. m. Overcast with sunshine near sunset. Swung ship both helms.
17	33 59 N.	223 51	178	Stiff breeze from SW. Overcast, with squalls a. m. Moderate sea.
18	35 43 N.	226 31	168	Moderate NW. breeze. Partly cloudy. Ship yawing badly. Heavy swells from NW.
19	36 30 N.	229 54	171	Moderate NW. breeze. Generally overcast. Heavy swells from NW. cause ship to yaw badly.
20	37 29 N.	232 05	120	Gentle NW. breeze. Sky overcast.
21	San Francisco.......		264	Moderate W. breeze. Overcast. Sighted land at 1 p. m. Entered Golden Gate at 7 p. m. and dropped anchor in San Francisco Bay at 8 p. m.

Total distance 5,765 miles. Time of passage, 46.1 days. Average day's run, 125.1 miles.

Summary of Passages for Cruise III of the Galilee.

TABLE 44.

Passage	Length of passage	Time of passage	Average day's run
	miles	*days*	*miles*
San Diego to Nukahiva......	3,220	26.7	121
Nukahiva to Tahiti..........	772	7.3	106
Tahiti to Apia..............	1,352	12.1	112
Apia to Yap.................	3,454	30.1	115
Yap to Shanghai............	1,734	15.1	115
Shanghai to Sitka...........	5,507	41.2	134
Sitka to Honolulu...........	2,708	18.3	148
Honolulu to Jaluit...........	2,728	23.8	115
Jaluit to Port Lyttelton......	3,436	43.1	80
Port Lyttelton to Callao.....	6,301	54.3	116
Callao to San Francisco......	5,765	46.1	125
Total.................	36,977	318.1	116

Summary of Passages for all Cruises of the Galilee, 1905–1908.

TABLE 45.

Cruise	Length of passage	Time of passage	Average day's run
	miles	*days*	*miles*
I, 1905..................	10,571	84	126
II, 1906..................	16,286	152	107
III, 1906–1908.............	36,977	318	116
Total.................	63,834	554	115

The total number of days the *Galilee* was in commission during the period August 1, 1905, to May 31, 1908, is 1,035. Since 554 days were spent at sea, the remaining days, 481, are to be ascribed to the time consumed at ports in swings of vessel, shore observations, computations, alterations and repairs, and outfitting.

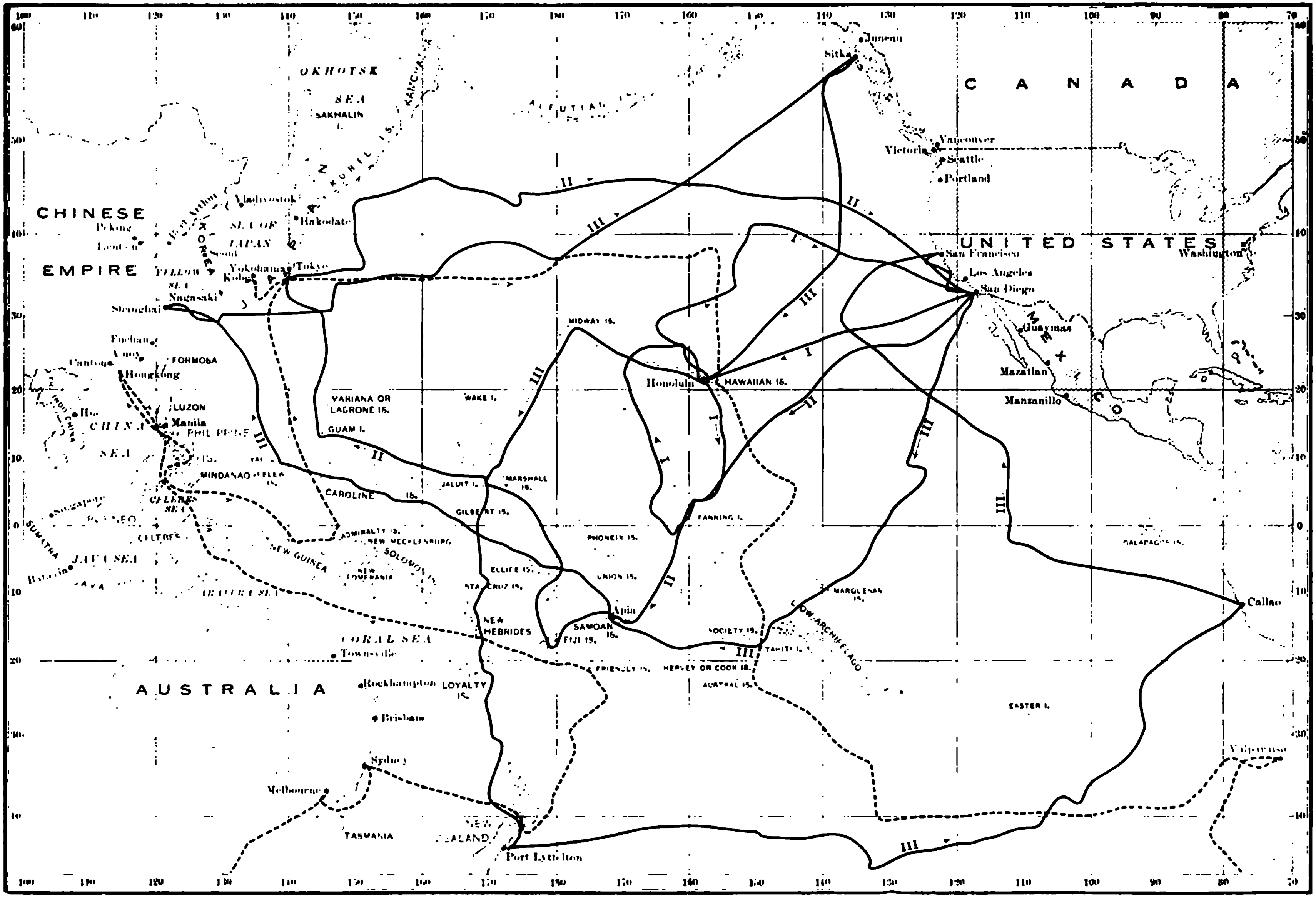
AUXILIARY OBSERVATIONS ON THE GALILEE.

Besides observations in terrestrial magnetism, the work aboard the *Galilee*, as far as time and conditions would permit, included atmospheric electricity during the second half of Cruise III. The results of the latter work will be found in the special report on results in atmospheric electricity (see pp. 364–366).

Observations were also made to determine the amount of atmospheric refraction by measuring the dip of the horizon with the dip-of-horizon measurer (Kimmtiefenmesser), made by Carl Zeiss, of Jena. A future special report will deal with this subject.

Meteorological observations have been made to the following extent: While at sea notes of the direction and force of wind were made at intervals of 4 hours. At the same time temperatures of the sea-surface and the air were recorded with readings of the wet-bulb thermometer. In addition to these usual meteorological notes, special observations were made at Greenwich mean noon according to the forms prepared by the United States Weather Bureau for observations at sea. The ship's aneroids were controlled by port comparisons with standard barometers whenever opportunity afforded.

The Greenwich-mean-noon meteorological observations, together with notes on allied phenomena (storms, polar lights, unusual meteorological events, etc.), have been regularly transmitted to the United States Weather Bureau for discussion along with the ocean data received by that Bureau from other sources.



Map Showing the Three Cruises of the Galilee, 1905–1908. (Broken lines show the tracks of the Challenger expedition, 1872–1876.)

THE MAGNETIC WORK OF THE CARNEGIE 1909-1916

BY

L. A. BAUER, W. J. PETERS, J. P. AULT, AND J. A. FLEMING

THE MAGNETIC WORK OF THE CARNEGIE, 1909-1916.

GENERAL REMARKS.

It was intimated on page 15 that with the steady improvement of the instrumental appliances and observational methods, the chief concern in accurate ocean magnetic work centered in the correct determination of the outstanding effects attributable to ship's magnetism. Hence arose the desire to have a strictly non-magnetic ship.

When the results of the magnetic observations made on the *Galilee*, 1905–1908, were finally deduced and the time and cost involved in the satisfactory determination and elimination of the ship's disturbing magnetic effects were considered, it was obvious that it would have been economy to postpone the inauguration of the ocean magnetic work if we had been certain at the outset that a non-magnetic ship would ultimately be provided. This assurance, however, in view of the uncertainties prevailing at the beginning, could not be given.

But now the desired ship—the *Carnegie*—has been obtained. Before passing, however, to an account of the work done on her since 1909, it will be of interest to review briefly the difficulties involved in making accurate observations on a moving support.

The accurate determination of the quantities required to define the direction and intensity of the Earth's magnetic field, at points on land where instruments may be mounted on fixed and stable supports, is a comparatively simple matter. Having properly designed instruments, and using approved observational methods, the trained observer's remaining difficulty on land is the adequate elimination of the natural fluctuations and changes taking place in the magnetic elements while he is measuring them. Fortunately, these magnetic fluctuations, except in rare instances, are of a very subordinate magnitude in comparison with the values of the measured quantities; for example, in the value of the horizontal component H of the intensity of the Earth's magnetic field, the fluctuations during the period of observation rarely amount to 0.2 per cent of the value of H. Only occasionally, when a severe magnetic storm is in progress, may there be momentary fluctuations amounting to 5 per cent of H. The effect of the changes occurring normally in the Earth's magnetic field may be reduced by the method of observation, and any outstanding portion can be determined with the aid of the data recorded at magnetic observatories.

The observer at sea must seek not only to reduce or eliminate the effects of the natural fluctuations in the Earth's magnetic field, referred to in the previous paragraph, but he must also endeavor to diminish the more troublesome effects caused by the fact that he is obliged to make his observations with a swinging instrument mounted on a moving and unstable support. Fortunately the observer aboard the *Carnegie* does not also have to contend with the difficulties introduced by a magnetic ship, as did the observer on the *Galilee*.

A ship at sea is never at rest and ever partakes of the motions of the element which supports it. In quiet waters the ship's motions are generally of such a nature that, with the proper instrumental appliances and observational methods, it is possible for a trained observer to make magnetic observations almost as accurately as they are made on land. The instruments are mounted on gimbals (see, *e. g.*, Pl. 14, Figs. 1 and 5) and all precautions are observed respecting control or elimination of error caused by any lack of precise level of instrument during observations. The observing method then consists chiefly in repetition of observations under varying conditions and for various reversals of instrument, or of magnet, for a period sufficiently long to eliminate the harmonic effects of the ship's motions. This is usually accomplished in 20 to 45 minutes, the time depending on the instrument used and the conditions encountered.

Ideal conditions for ocean magnetic work are not necessarily periods of calms. During such times a vessel depending chiefly on sail power for headway can not hold a steady course. In consequence, frequent and rapid re-settings of instruments are required or else the changes in the headings of the ship must be continuously recorded and allowed for in the computations.

Under the usual conditions at sea, observations are more or less difficult, owing to the effects produced by the rolling, pitching, and yawing of the vessel. Were one to wait for ideal conditions, many days would elapse between observations, and long stretches, barren of results, would occur in a voyage. Accordingly, instruments and methods must be designed and planned to meet, at least, the usual conditions and to secure the accuracy required for both practical and scientific purposes. Instruments should be designed with a view to diminishing the probable dynamic effects in the observational results produced by the ship's motions. Improvements in this direction are possible to a certain extent by avoiding unsymmetrical distribution of mass in magnets about their centers of motion. The practical application of this principle is limited, however, by the changing values of the magnetic elements as the vessel sails from place to place.

In order to make observations in all conditions of sea and weather, the instrument and observer must be effectively sheltered from storm, direct sun rays, and spray. The stand with its gimbal rings to receive the instrument must be oriented carefully with outer trunnions athwartship. The instrument is finally mounted and leveled while the vessel is in quiet waters. It is then ready for use under sea conditions, as nearly perfect as is at present possible.

The specimens of observations on pages 212–225 and discussions, pages 434–437, will serve to give some idea as to how well the difficulties caused by ship's motions have been overcome.

All the effects above briefly discussed, whether caused by natural fluctuations or artificial ones introduced by a moving vessel, while all of sufficient magnitude to be taken into consideration, are, in terrestrial magnetism, generally of a subordinate nature to the values of the primary quantities themselves. In atmospheric electricity, however, the fluctuations resulting from both natural and artificial causes are of the order of magnitude of the primary elements measured. The observational difficulties in this subject will be found discussed in a special report (see pp. 361–422).

The name given to the vessel, *Carnegie*, was the result of careful consideration. At one time it was proposed to call the vessel the *Franklin*, which would have been quite appropriate in view of the interest in physical science of the illustrious pioneer investigator of atmospheric electricity. However, there were already several vessels named *Franklin* and it was finally thought best to give the magnetic-survey vessel a name which would identify her specifically with the institution to which she belongs.

August 21, 1909, the builder formally turned over the *Carnegie* to the Director of the Department of Terrestrial Magnetism, acting in behalf of the Institution, and on this day she entered on her trial cruise. Thus, in 15 months from the cessation on June 1, 1908, of the ocean work begun in the Pacific Ocean on the *Galilee* in 1905, a new and special vessel had been built and fully equipped, and the ocean magnetic survey could be resumed.

DESCRIPTION OF THE CARNEGIE.

The principal dimensions of the *Carnegie* are: Length over all, 155 feet 6 inches; length on load water-line, 128 feet 4 inches; extreme breadth, 33 feet 6 inches; depth of hold, 12 feet 9 inches, with a mean draft of 12 feet 7 inches,[1] and a displacement of 568 tons with all stores and equipment on board. Her lines, as will be seen from the frontispiece and Plate 7, Figure 3, and Plate 15, Figure 1, are fair and easy, running in an unbroken sweep from stem to stern, and showing strength and seagoing qualities throughout. (See also Figs. 8 and 9.)

All the materials entering into the construction of the vessel are non-magnetic and are the very best of their kind. The hull is constructed as thoroughly and substantially as any merchant vessel afloat, the scantlings being the same as those required by the American Bureau of Shipping for merchant vessels of equal tonnage. The keel, stem, stern post, frames, and dead-wood are of white oak, grown, cut, and sawed in Greater New York—at Jamaica Plains—within 12 miles of the place where the vessel was built; the deck beams, planking, and ceiling are of yellow pine, and the deck is of Oregon pine in long lengths, comb-grained. The keel (see Fig. 9 and Pl. 8, Fig. 5) is 12 by 18 inches, and to this is fitted a false keel, 12 by 4 inches. There are two center keelsons, each 12 by 14 inches, and two assistant keelsons, 12 by 12 inches. The garboard strakes are 6 by 12 inches, rabbeted into the keel. The planking on the bottom is 3 inches thick; at the bilge 4 inches, and on the sides 3½ inches. The ceiling in the bottom is 3 inches thick, at the bilge 6 inches, and on the sides 4 inches. The main deck beams are 8 by 10 inches, with a crown of 3½ inches at the center of the ship. They are joined to the frames with hackmatack knees of 8-inch siding.

The fastenings consist of locust treenails, copper and Tobin-bronze bolts, and composition spikes, all through bolts being riveted over rings, both inside and outside. All metal deck fittings and the metal work on the spars and rigging are of bronze, copper, and gunmetal (see Pl. 10).

The vessel has full sail power with a brigantine rig, carrying just under 12,900 square feet of plain sail. Her spar plan measures 122 feet from foremast truck to the water surface, and 201 feet from the forward end of the bowsprit to the aft end

[1] This was increased in 1914 about 15 inches.

of the main boom. The distance from the forward end of the bowsprit to the forward end of the load water-line is 48 feet; from the forward end of the load water-line to the foremast 35 feet; from the foremast to the mainmast 48 feet. The rigging is of Russian hemp. Figure 8 shows the sail plan. (See also Plate 7, Figure 3, Plate 8, Figure 1, Plate 15, Figure 1, and Plate 17, Figures 2 and 5.)

It was decided to install auxiliary propulsion for use in entering or leaving ports and to prevent interruptions in the observations by maintaining desired headway during calms. The necessity of providing auxiliary propulsion which would be nearly non-magnetic in character made the selection of the type of the plant a rather difficult matter. Steam was precluded on account of the necessarily high magnetic nature of a steam plant. The only type of prime mover at the time (1909) which could be economically built and maintained in reliable operation with a minimum of non-magnetic metals in its construction appeared to be an internal-combustion engine. (See Pl. 8, Figs. 2–5.)

FIG. 8.—Sail Plan of the Carnegie.

Consideration of the available fuel for such a motor resulted in the elimination of gasoline or oil, not only on account of cost, but also because they would be usually unavailable in the zones to be covered by the *Carnegie*, as well as dangerous in the quantities which would have to be stored for the lengthy voyages contemplated. A careful investigation showed that a gas-producer for marine purposes could be built which would generate from anthracite coal a suitable gas for use in internal-combustion engines and that such a plant could be constructed almost entirely of non-magnetic materials. The suction type of gas-producer was adopted, principally because of its simplicity in construction and operation and on account of eliminating as much as possible other auxiliary apparatus.

A 4-cylinder Craig internal-combustion engine of 150 horsepower (Pl. 8, Fig. 4), sufficient to give the vessel a speed of 6 knots in calm weather, was installed. The gas-producer was furnished by the Marine Producer-Gas Company of New York and consists of a cylinder 6 feet high with a diameter of 5 feet 6 inches, built of copper, with asbestos and firebrick lining and manganese-steel grates. Anthracite coal is used as fuel, the gas being generated in the producer, taken through a "scrubber," and used explosively in the internal-combustion engine. The vessel carries 30 tons of coal in her bunkers. Non-magnetic manganese steel was used for the doors, grate, and small parts of the producer. The only magnetic material used in the construction of the bronze engine is in the steel valves, piston-rings, cam-springs, and cam-rollers. The total magnetic material was less than 600 pounds. Plate 8, Figures 2–5, shows the various parts and general arrangement of the power plant.

FIG. 9.—Inboard Profile, General Arrangement, and Deck Plan of the Carnegie.

The ground tackle comprises 4 manganese-bronze anchors of special design—2 being of 1,900 pounds each, 1 of 1,335 pounds, and a kedge anchor of 340 pounds. Three 11-inch cables, each 120 fathoms in length, are required for these anchors. The hawse-pipes, boat davits, chain plates, and all metal deck fittings are of bronze. A fisherman's windlass (see Pl. 10, Fig. 4, and Pl. 18, Fig. 2), constructed of wood and brass, is used to weigh anchor. (A view of propeller blades is shown on Pl. 17, Fig. 3.)

The boat equipment consists of two non-magnetic 20-foot whaleboats and one 16-foot non-magnetic gig (see Pl. 9).

There was provided a refrigerating plant constructed of bronze and copper and operated by a 6-horsepower engine, especially designed and built of brass and bronze.

All living quarters are below, the ventilation and lighting being obtained by means of a cabin trunk on deck about 42 feet 8 inches in length, 16 feet 6 inches in width and 3 feet in height, and safety is secured by means of 6 transverse watertight bulkheads dividing the vessel into 7 compartments. The sailing officers' and crew's quarters are forward, 42 feet in length and occupying the full width of the vessel; next are the quarters for the scientific staff, 38 feet in length and extending the full width of the vessel; and abaft of these is the machinery space, 23 feet in length. The living quarters have been planned to give good accommodations for all, and are fitted with the necessary conveniences for long cruises. Figure 9 gives the inboard profile of the *Carnegie* and shows the general arrangement of the vessel and her deck plan. (See also Pls. 9, 10, and 15.)

There are 2 galleys, one aft for the scientific personnel and the other forward for the watch officers and crew, especially designed cooking ranges of bronze and copper being provided. The galley utensils are made of aluminum or copper and the cutlery is of Mexican silver.

Of special interest is the observation room, or deck house, located on the main deck amidships, forward and aft of which are circular observatories with revolving domes not unlike those of astronomical observatories (see Pls. 7, 9, 15, and 16).[1] It is thus possible to make magnetic observations both in the open and under shelter. The observation room is 14 feet 6 inches long and 16 feet wide. The observatories are circular, 7 feet 6 inches in diameter, each fitted with a revolving dome, constructed of bronze framework and plate glass so arranged as to permit sighting, whenever desirable, on celestial or terrestrial objects in magnetic-declination work. The joiner-work is of white pine, painted, with hardwood trimmings finished bright.

The positions of the stands for the various instruments have been so chosen that any effect resulting from the small amount of iron in the engine, which could not be replaced by non-magnetic material, is negligible. (See pp. 202–203.)

To eliminate further any possible magnetic effect, empty spaces are arranged around and below the instrument stands, making it impossible for any one, except the observers, to come closer than about 8 feet to the magnetic instruments while observations are in progress.

The total cost of the *Carnegie*, fully equipped, approximated $115,000.

[1]In 1915 there was added abaft the after observing-dome an observation-house for the atmospheric-electric work (see p. 376 and Pl. 22, Fig. 1).

SYNOPSES OF THE CARNEGIE'S CRUISES, 1909-1916.

CRUISE I, SEPTEMBER 1909 TO FEBRUARY 1910.

During the period August 21 to September 10, 1909, various tests and trials of the vessel were made in Long Island Sound and Gardiners Bay, and some alterations to machinery were effected at New London, Connecticut; the *Carnegie* left the latter place on September 11. The swing observations for the purpose of testing the absence of observable deviations were made in Gardiners Bay from August 31 to September 2. W. J. Peters, who had been in charge of the *Galilee* during Cruises II and III, was placed in command of the *Carnegie*. He was assisted by J. P. Ault, magnetician; C. C. Craft, surgeon and observer; E. Kidson and R. R. Tafel, observers; and D. F. Smith, chief engineer. The sailing staff consisted of C. E. Littlefield, sailing master; 2 watch officers; 8 seamen; 1 mechanic, and 2 cooks. During the trial period of the installations on the *Carnegie* in Long Island Sound and on the trip to St. John's, the Department was fortunate in securing also the temporary services of Carl D. Smith, expert in gas engines. The Director accompanied the vessel on the trip from St. John's, Newfoundland, to Falmouth, England. (For views referring to Cruise I, see Pl. 7, Figs. 3-5.)

Encountering headwinds and calms, the *Carnegie* arrived at St. John's, Newfoundland, on September 25, entering the harbor with her own power. After the completion of the shore work at St. John's, the vessel left on October 2, bound for Falmouth. The passage, in general, was rough, westerly gales being an almost daily experience; still the trip was made in less than 12 days, the average daily run being 159 nautical miles. Magnetic observations were secured on every day but one. On October 18 the vessel was swung outside of Falmouth Harbor, the results confirming those at Gardiners Bay and proving most satisfactorily that non-magnetic conditions had, indeed, been secured at the various positions for the instruments. The results were also in excellent agreement with those derived from the Rucker and Thorpe magnetic survey of the British Isles, when referred to date of observation with the aid of the records of the Falmouth Magnetic Observatory. This Observatory rendered valuable assistance in various ways.

Both at St. John's and Falmouth the *Carnegie* was visited by eminent persons. The Governor and the Premier of Newfoundland made special visits, and at Falmouth official visits and inspections were made by the late Sir Arthur Rucker and Professor Arthur Schuster, both at the time members of the Advisory Council of the Department, as also by Commander Chetwynd, superintendent of the Compass Department of the British Admiralty. Special courtesies were extended to the vessel at both ports. As she left St. John's, messages of farewell and of wishes for a pleasant voyage were hoisted on H. M. S. *Brilliant* (Capt. Haworth Booth in command), and on Cabot Tower on Signal Hill, above the narrow entrance to the harbor.

The *Carnegie* left Falmouth, England, upon the completion of the work there, on November 9, 1909, and arrived at Funchal, Madeira, on November 24. Owing to the pronounced local disturbances at Funchal, no standardization observations were made. The longest passage of the *Carnegie's* first cruise, viz, between Funchal and Hamilton, Bermuda, was completed between December 1, 1909, and January 7, 1910, under very favorable conditions for observing. The constants of the instruments were determined at Agar's Island and Hunt's Island and the final passage of the first cruise to New York was begun on January 28, 1910. After a very stormy trip, which proved the seaworthiness of the vessel, the *Carnegie* came to dock in Brooklyn on February 17, 1910.

Owing to the great advantage of having a vessel requiring no deviation-correction whatsoever, and because of the perfection reached in the instruments themselves, it was possible, for the first time, to make the results known immediately upon the conclusion

of a voyage. Thus the magnetic data obtained on the trip from Long Island Sound to Falmouth (September 1–October 18) were communicated, on arrival of the vessel at Falmouth October 2, to the leading hydrographic establishments of the world, were laid before the Russian Geographic Society at Petrograd by General Rykatchew on October 27, and were published in *Nature* on October 28.

Errors of importance to the navigator were found on the *Carnegie's* first cruise. Thus, along the track followed by the Atlantic liners from England to a point off Newfoundland, the magnetic charts, in general, showed too large westerly declination (variation of the compass), the error reaching nearly a degree. From there to Long Island the charts gave systematically too small westerly declination or variation of the compass, by amounts reaching 1°.5 in the maximum. Owing to the peculiar and systematic nature of the errors, their effect was always to set a vessel toward Sable Island or Newfoundland, when her course had to be shaped entirely by compass and log, as is the case in time of fog or cloud. Some of the skilled captains of our ocean liners had suspected the possibility of such errors, but the *Carnegie* definitely proved and published the fact and revealed the cause. For long stretches on other portions of the cruise, systematic and, hence, cumulative errors were disclosed, the mariners' charts of the compass direction being found in error at times as much as 2° to 2°.5.

The chart errors in magnetic dip amounted to 1°.5 to 2°.5, and in the horizontal component of the Earth's magnetic force the error at times reached nearly one-tenth part. The errors found in the three magnetic elements were partly due to errors in the assumed values of the secular variation.

The total length of Cruise I was 9,600 nautical miles; the time at sea (not counting stoppages at ports) was 96 days; hence, the average day's run was 100 miles. (See abstract of log and summary, pp. 330–332.)

CRUISE II, JUNE 1910 TO DECEMBER 1913.

The alterations and additions found desirable as the result of the first cruise were completed in time to permit the *Carnegie* to set out from Brooklyn upon a three-years' circumnavigation cruise on June 20, 1910, under the command of W. J. Peters. In connection with these alterations, which were almost wholly in the auxiliary propulsion plant and its general arrangement, acknowledgment must be made of the cordial and effective assistance rendered by the architect of the *Carnegie*, H. J. Gielow; by the constructing firm, the Tebo Yacht Basin Company, then under the management of Wallace Downey; by C. D. Smith and W. C. Bauer, consulting engineers; by James Craig, Jr., the builder of the engine; and by D. F. Smith, the engineer-in-charge.

The *Carnegie* first proceeded to Greenport, Long Island, and swung ship in Gardiners Bay on June 22, 23, and 25, at the same place as in the preceding year. She was visited and inspected at Greenport by President Woodward in company with the Director. Having completed the determinations of instrumental constants, course was set on June 29 for Vieques, Porto Rico, via latitude 34° north and longitude 46° west. After an unusually favorable passage, during which observations of the three magnetic elements were possible on all but two days, Vieques was reached on July 24. Through the courtesy of Superintendent O. H. Tittmann, of the United States Coast and Geodetic Survey, opportunity was afforded, at this point, to compare the *Carnegie* magnetic instruments with the standards of the Vieques Magnetic Observatory, the local observer, G. Hartnell, assisting in every way. The anchorage at Vieques was exposed, so, while the observations were being made at this place, the vessel anchored at Culebra Island, and the observers lived ashore. Upon completion of the comparisons, the vessel returned to Vieques to take on the observers, and then, having made magnetic observations at the Culebra station for secular-variation data, the expedition proceeded to Porto Rico, where valuable assistance

was rendered by Commodore Karl Rohrer, of the United States Naval Station. The *Carnegie* left San Juan, Porto Rico, for Para, Brazil, where she arrived September 24, 1910, having encountered unusually favorable conditions for magnetic work. Upon completion of the shore work at Pinheiro, the magnetic station near Para, the *Carnegie* left on October 15, 1910, and arrived at Rio de Janeiro, Brazil, December 2, 1910, the voyage having been made under very favorable observing conditions. Intercomparisons of barometer standards were carried out at the Rio de Janeiro Observatory through the courtesy of Director Morize, who also rendered the *Carnegie's* scientific staff valuable aid in other ways. Upon the completion of the usual harbor intercomparisons of land and ship instruments and swing observations on December 23 and 24, the *Carnegie* sailed on December 29 for Montevideo and Buenos Aires. (For view of shore work at Rio de Janeiro, see Pl. 19, Fig. 1.)

No land observations were made at Montevideo, at which place the *Carnegie* arrived on January 14, 1911. After a short delay by storm she proceeded to Buenos Aires, arriving there January 17. The observing conditions between Rio de Janeiro and Buenos Aires were very good, and numerous observations were obtained. The comparisons of ship and land instruments, as well as the comparisons of the Argentine magnetic standards with those of the Department, were carried out at the magnetic observatory of the Meteorological Service of Argentina at Pilar, Cordoba. Barometer comparisons were also made at the office of the Meteorological Service in Buenos Aires. Acknowledgment is made here of the cordial cooperation and effective aid received from Director W. G. Davis and the observer-in-charge at Pilar, L. G. Schultz.

The *Carnegie* sailed from Buenos Aires on February 14; but on account of adverse winds and tidal conditions, together with the loss of an anchor, subsequently recovered, she did not get out of the Rio de la Plata into the open sea until the 21st. Owing to this delay and to foggy weather in the vicinity of Tristan da Cunha, it was found impracticable to stop at this island, as had been planned, so that practically a great-circle course was followed between Buenos Aires and Cape Town. This portion of the cruise was very successful and numerous magnetic observations were made, despite the foggy conditions prevailing during a part of the time. Cape Town was reached March 20. Intercomparisons of the land and sea instruments, as well as comparisons with the magnetic outfits of Professors J. C. Beattie and J. T. Morrison, were secured at Valkenberg, near Cape Town. Barometer comparisons were made with the standards of the Royal Observatory, Cape of Good Hope. At Cape Town Dr. H. M. W. Edmonds, surgeon and magnetician, and Observer H. F. Johnston joined the vessel. Dr. C. C. Craft, who had been surgeon and magnetic observer on board the *Carnegie* since the initiation of her work, was relieved of sea duty at Cape Town to return to the Office, owing to the impaired condition of his eyes.

Upon the completion of the observations at Cape Town, where Doctors Beattie, Dodds, and Hough rendered much valuable aid, the *Carnegie* left for Colombo on April 26, arriving there June 7, 1911. The course from Cape Town was made for St. Paul Island, and thence directly for Colombo. This passage of the cruise was accomplished with cloudy weather and heavy seas during the easterly course, and under fine conditions during the northerly course. Observations were made nearly every day. At Colombo the Director joined the vessel for the purpose of a general inspection trip, for consultation with the commander as to the details of the work, and for discussion regarding such alterations as might be deemed advisable for further improvement. Observer E. Kidson, who had been on duty aboard the *Carnegie* since the initiation of her work in 1909, was relieved at Colombo of sea duty, and directed to proceed at once to Australia, there to take up magnetic-survey work on land. Numerous courtesies were extended to the *Carnegie* staff by the officials at Colombo.

Having completed the intercomparisons of the land and sea instruments at Colombo, and of the barometric standards at the Meteorological Observatory, the *Carnegie* set sail

on July 6, 1911, for Port Louis, Mauritius Island, with the Director aboard, arriving there August 5, on schedule time. With the exception of a few days this portion of the cruise was made under very favorable conditions. Valuable data, both with regard to the distribution of the magnetic elements and their secular changes, were secured, the course to Mauritius being deflected to the southward in order to intersect the track of the *Gauss*. On this portion, also, the 1911 track of the *Carnegie* northward to Colombo from St. Paul Island was crossed, and thus valuable opportunity was afforded for testing the accuracy of her work, as well as of the chart errors previously found. The results of these tests were very satisfactory. Intercomparisons of land and sea instruments, as well as a valuable intercomparison of the standards of the Department and those of the Royal Alfred Observatory, were secured. Much interest was shown in the work of the *Carnegie* by the Governor of Mauritius and other officials. Director Walter, of the Observatory, rendered valuable aid in the instrumental comparisons. (See Pl. 15, Figs. 1 and 2.)

The land work being completed, the *Carnegie* left Port Louis, bound for Batavia via Colombo, on August 16, 1911, the Director continuing with the vessel. A short stop was made at Colombo, during September 10 to 15, and there the Director left the party to visit magnetic organizations and observatories in India, the East Indies, and China. Excellent conditions prevailed between Mauritius and Colombo, and numerous observations were made. After a 43-day cruise from Colombo, during which the desired observations were secured, Batavia was reached on October 27, 1911. The course from Mauritius carried the vessel first to the westward of the Seychelles Islands into the western part of the Arabian Sea, where the agonic line was located by two widely separated crossings, and across the tracks of the principal steamship lines, thence back to Colombo, and from there to Batavia. Intercomparisons of the sea and land instruments, as well as valuable intercomparisons of the standards of the Department and those of the Royal Meteorological and Magnetic Observatory, were secured at Batavia, through the effective assistance of Director van Bemmelen. (For view of work in atmospheric electricity, see Pl. 15, Fig. 4.)

From Batavia the *Carnegie* sailed on November 21, 1911, bound for Manila by a circuitous route, arranged so as to cover the eastern part of the Indian Ocean. The course followed was south-southwest in the Indian Ocean to south latitude 30°.8 and east longitude 89°.4; thence it extended to 37°.5 south, in east longitude 95°.5. From this point a general northeasterly course was followed into the China Sea and the North Pacific. The *Carnegie* reached Manila, Philippine Islands, on February 2, 1912, having been out 73½ days from Batavia, and having covered a distance of 8,291 miles; the conditions for observations were good.

At the new Manila Magnetic Observatory, situated at Antipolo, intercomparisons of magnetic instruments were made with the standards of the United States Coast and Geodetic Survey and with those of the Antipolo Magnetic Observatory. These comparisons were much facilitated through the cordial cooperation of Director Algué of the Manila Observatory and his chief assistant at the Antipolo Observatory, M. Saderra Masó, and the Director of Coast Surveys at Manila, P. A. Welker, at the time. Upon the completion of the land work and of minor repairs in dry dock, the *Carnegie* left Manila on March 24, 1912, pursuing a northeasterly course off the Luchu Islands, and thence practically due east to north latitude 30° and east longitude 166°. Thence the course was, in general, southward to Suva, Fiji Islands, where the vessel, after having been considerably delayed by head winds, arrived June 7, 75 days out from Manila. The total distance covered from Manila to Suva was 8,158 miles. The track of the *Galilee* was crossed several times, and thus valuable secular-variation data were obtained. Effective assistance was rendered the *Carnegie* at Suva by various officials.

Upon completion of the land work at Suva, including a reoccupation of the *Galilee* station of 1906, the *Carnegie* left for Papeete, Tahiti, June 30, 1912. The departure

from Suva was delayed by contrary winds blowing through the narrow entrance. A course was steered along the parallel 30° south, passing between the outward and homeward-bound passages of the *Galilee's* last cruise. From near Easter Island a northerly course was followed to the equator; thence the course was westerly, and then southwest to Tahiti. On crossing the equator, the ship was swung under favorable conditions for magnetic inclination and intensity. The observations, made on the various headings in the two observing domes, again showed smaller differences among themselves than the general accuracy of sea observations.

Papeete, the port of Tahiti, was reached September 11, 1912; here the acting governor and other officials took great interest in the *Carnegie* and her work. On October 15, after completion of the land work, the vessel sailed for Coronel, Chile, where she arrived on November 25. The magnetic station established at this place in 1907 by the *Explorer*, of the United States Coast and Geodetic Survey, was reoccupied. After the necessary land observations had been made for the determination of constants and intercomparisons of instruments, the *Carnegie* proceeded to Talcahuano on December 4. At this port, through the courtesy of the Chilean naval officials, particularly Admiral Francisco Neff, the government dry-dock was used for dry-docking the vessel and carrying out necessary repairs. While at Talcahuano opportunity was given Observers Hewlett and Johnston to visit Dr. Walter Knoche, in charge of the meteorological work for the Chilean Government at Santiago, and to discuss with him methods of work in atmospheric electricity at sea. Subsequently Dr. Knoche visited the *Carnegie* at Talcahuano and kindly made some further suggestions.

Leaving Talcahuano December 19, 1912, the *Carnegie* proceeded next to Stanley, Falkland Islands, arriving there January 27, 1913. A northwest course was followed to about 26° south latitude and 95° west longitude, thence southwest to about 40° south latitude and 107° west longitude, and thence around Cape Horn to Stanley. Winds of great strength prevailing for days at this port, considerable delay was experienced in the completion of the work, which included a reoccupation of the magnetic station given in the "British Admiralty List." Dr. Edmonds was relieved of ocean duty at Stanley in order to take charge of a land expedition to Hudson Bay, and Dr. C. C. Craft was assigned as surgeon and magnetic observer in his place. Acknowledgments are due the Governor of the Falklands, Honorable W. L. Allerdyce, and other officials and persons at Stanley for numerous kindnesses shown.

The *Carnegie* sailed from Stanley on February 22, 1913, bound for St. Helena, following a great-circle route to 46°.5 south latitude and 1° east longitude. Along this portion of the passage a number of large icebergs were seen. The 1911 track of the *Carnegie* was crossed, as well as that of the *Gauss* while on her Antarctic cruise. The *Carnegie* was swung at sea on March 21, and it was once more found that the magnetic observations (magnetic inclination and intensity), made on the various headings, agreed with each other within the observational errors. Arriving at Jamestown, St. Helena, on April 3, the stop made this time was only long enough to provision the vessel, attend to the accumulated correspondence, and dispatch the observation records to Washington. In order to make the more southerly return passage from Bahia to St. Helena before the Sun reached the summer solstice, as had been planned, the usual shore work was postponed, and St. Helena was left on April 9, the course being set direct for Bahia. En route, observations of the magnetic declination were made during a complete swing of the vessel, confirming the absence of possible deviations greater than the error of observation.

Bahia was reached on April 24. As the Brazilian station at Bahia was no longer suitable for secular-variation purposes, a new magnetic station was established on Jaburu Point (Pl. 19, Fig. 2) where intercomparisons were made ashore of all instruments used

aboard. Observer Schmitt joined the *Carnegie* at this port in place of Observer Johnston, who had been assigned to take charge of important land magnetic work in Paraguay, Uruguay, Argentina, and Brazil.

After completion of the land work, the *Carnegie* sailed from Bahia on May 19 for St. Helena, following a south and east course to about 33° south latitude and 8° west longitude, and sailing thence north to St. Helena, where she anchored off Jamestown, June 23. On this passage considerable cloudy and stormy weather was experienced. Complete intercomparisons of all instruments were now made ashore, and one magnetic station of the *Gauss* expedition was reoccupied. The Governor of St. Helena (Major H.W. Cordeau), at both visits of the *Carnegie*, evinced his interest and extended various courtesies.

Leaving St. Helena on July 21, a north-northwest course was followed to about 30° north latitude and 40° west longitude, and then north and northeast courses to Falmouth, where the vessel arrived September 12. On August 15 and 18, magnetic observations were obtained on 8 equidistant headings of the ship, the previous conclusions regarding absence of appreciable ship deviations being again confirmed.

During this passage from St. Helena to Falmouth, the *Carnegie* on August 10 crossed her track of 1909. A comparison of the two values of the magnetic declination obtained at the point of intersection, one in 1909 and the other in 1913, showed that the north end of the compass needle had shifted westward at an average annual rate of 7 minutes; this is in the right direction to account to some extent for chart errors. A reliable value of the secular change, derived from sea observations for an interval of not quite four years, can only be obtained by means of the refined methods and instruments in use on the *Carnegie*.

At Falmouth, besides the usual shore comparisons of instruments, the stations established by the *Carnegie* during her first call at this port in October 1909, at Trefusis Point and St. Anthony, were reoccupied for the purpose of determining the secular change in the magnetic elements since 1909. For the same purpose magnetic observations were made at the two nearest stations, Truro and Porthallow, of the Magnetic Survey of Great Britain by Professors Rucker and Thorpe; thus additional data for connecting the latter survey with the work of the *Carnegie* were obtained. The vessel was also swung a second time in Falmouth Bay, complete magnetic observations being made over the same area where similar work was done in 1909; the 1909 results were confirmed. In connection with the *Carnegie's* work at Falmouth, acknowledgment should be made of the aid received from Doctors Glazebrook and Shaw, and Messrs. W. L. Fox, J. B. Philipps, and Spry.

October 15, the *Carnegie* left Falmouth on the last passage of the long cruise begun in June 1910. On account of head winds she put in at New London, Connecticut, on December 14, and was towed to Greenport on December 15. After reoccupying the repeat stations at Greenport and Shelter Island, the *Carnegie* left on December 18 and was berthed at Beard's Yacht Basin, Brooklyn, on December 19. The Director inspected the vessel here, and conferred with W. J. Peters, commander, regarding the repair work required after the three-year continuous cruise of the *Carnegie*.

The *scientific personnel* on this cruise, besides the Director, who was with the vessel from June to September 1911, consisted of the following persons: W. J. Peters, in command of vessel; C. C. Craft, surgeon and observer to April 1911 and from February 1913; H. M. W. Edmonds, surgeon and magnetician, from March 1911 to February 1913; E. Kidson, observer, to June 1911; H. D. Frary, observer, to September 1912; C. W. Hewlett, observer, from September 1912; H. F. Johnston, observer, from March 1911 to May 1913; H. R. Schmitt, observer, from May 1913; C. R. Carroll, meteorological observer and clerk, to September 1911; N. Meisenhelter, meteorological observer and clerk, from February 1912. (For view of the *Carnegie's* personnel, see Pl. 15, Fig. 3.)

At the various ports of call the *Carnegie's* scientific staff received most cordial assistance from various diplomatic and consular officers besides from those already mentioned.

Besides the usual observations for geographic position and of the magnetic elements, atmospheric-electric observations, as opportunity afforded, were made on the *Carnegie* by Observers Kidson and Johnston. Atmospheric-pressure observations have been carried out and various improvements in the method of observations were effected. Observations for atmospheric-refraction effects at sea were also made.

The total length of Cruise II was 92,829 nautical miles; the time at sea (not counting stops at ports) was 798 days; hence, the average day's run was 116 miles. (See abstracts of log, pp. 333–347, and summary, p. 347.)

CRUISE III, JUNE TO OCTOBER 1914.

Upon the return of the *Carnegie* from her long circumnavigation cruise (Cruise II) arrangements were promptly made for the necessary repairs, required chiefly on account of dry rot. At the same time some alterations in the interior arrangements of the vessel were made. The stone ballast, previously used, was replaced by lead ballast. The refrigerating plant, oil engine, and producer-gas engine were also overhauled, and some improvements were effected. The repairs and alterations were made at Hoboken, New Jersey, by Tietjen and Lang, under the direct supervision of W. J. Peters, as representative of the Department of Terrestrial Magnetism.

Meanwhile, plans had been made for a cruise, under the charge of W. J. Peters, chief of party, to Hudson Bay in a chartered vessel, the *George B. Cluett*, belonging to the Grenfell Association. Accordingly, on June 1, 1914, the command of the *Carnegie* was transferred to J. P. Ault, who has carried out the cruises of the vessel since that date.

After the Director had made his inspection of the vessel, and had given the final instructions regarding the cruise and the program of work, the *Carnegie* left Brooklyn, on June 8, 1914, direct for Hammerfest, Norway, with the following personnel aboard: J. P. Ault, magnetician and in command of vessel; H. M. W. Edmonds, magnetician and surgeon; H. F. Johnston and I. A. Luke, observers; N. Meisenhelter, meteorological observer and clerk; R. E. Storm, mechanical engineer; J. Sahlberg, J. Johnson, and T. Pedersen, watch officers; C. Heckendorn, mechanic; 8 seamen, 2 cooks, and 2 cabin boys; 22 persons in all. Martin Clausen, who had served faithfully and efficiently, first as third and later as second and first watch officer on the previous cruises, on May 17, during shore leave, unfortunately met with an accident, and died on May 24. On May 27 John Sahlberg was appointed first watch officer in his stead.

From Brooklyn, the *Carnegie* followed a course practically due east along the parallel of 41° north to about 53° west longitude, and thence practically in a direct line to Hammerfest. A landfall was made in the vicinity of the Faroes on June 27. Hammerfest was reached on July 3, after a cruise of 4,152 nautical miles. In addition to the usual stations occupied at Hammerfest for the purpose of determining the instrumental constants, observations were secured in the neighborhood, at five additional stations, for the purpose of selecting a suitable place in the harbor to swing the vessel, and thus test anew the absence of ship deviations at the mounts of the magnetic instruments. Swings of vessel were secured on July 15, 16, and 18, with satisfactory results for both horizontal intensity and inclination, as also for declination, due account being taken of the small horizontal intensity (0.1 C. G. S.) at this high magnetic latitude. These tests showed once more, as in the previous cruises, that there are no deviations of sufficient magnitude to be taken into account. (See Pl. 16, Figs. 2 and 3, and Pl. 19, Fig. 3.)

On July 25 the *Carnegie* left Hammerfest, bound this time for Reykjavik, Iceland, the commander's instructions being to proceed as far north as ice conditions permitted, without

endangering the safety of the vessel. The following interesting extract is taken from his report, dated Reykjavik, August 27, 1914:

"After leaving Hammerfest it was planned to make a short trip into the Barents Sea towards Nova Zembla, but, head winds being encountered, the course was shaped for Spitzbergen. We were becalmed 2 days off Bear Island, after which fair winds prevailed until July 31, when ice was sighted about 30 miles south of South Cape, the southernmost point of Spitzbergen. A few hours later we were headed off by the solid ice-pack, but the western edge of the pack could be seen and we knew that by standing to the westward it would be possible to clear it. This flow did not extend far into the sea west of Spitzbergen, having drifted down from Stor Fiord to the eastward of Spitzbergen. Standing to the westward, we cleared the ice, and, being favored with fair winds and good weather, continued northward.

"On August 2, all plans were made to swing ship the next day north of latitude 80°, the engine being in running order. That night the southwesterly wind increased to a gale, making it necessary for us to heave-to and try to get south, as the solid polar ice-pack was only about 50 miles to the northward. Our farthest north, therefore, was latitude 79° 52ʹ.3. After 4 days of head winds we again had favorable winds, but for 4 days we saw nothing of the Sun, and consequently secured no magnetic-declination observations. Off the northeast coast of Iceland another head wind was encountered, which lasted 7 days.

"On August 21, the day of the eclipse, we had our first clear weather for 2 weeks and had a fine view of the eclipse, getting numerous photographs and noting times of contact. From there to Reykjavik, where we arrived on August 24, the trip was without incident, with the exception of 2 days of head winds, just before entering the harbor."

On account of local disturbances in the general neighborhood of Reykjavik, it was not deemed worth while to attempt swings until after leaving Reykjavik. Various shore stations were occupied, as also Dr. Angenheister's station of 1910. The necessary shore observations and standardizations of the ocean instruments having been completed, the *Carnegie* sailed from Reykjavik on September 13, bound for Greenport, Long Island. She arrived at the latter port on October 12; after the completion of the shore and harbor observations, both in terrestrial magnetism and atmospheric electricity, she proceeded to Brooklyn and was berthed at Beard's Yacht Basin on October 21. (See Pl. 16, Fig. 5.)

The *Carnegie*, on this cruise, thus reached a high northerly latitude and secured a valuable series of observations in a region of high magnetic latitude. The largest value of the magnetic inclination was 81°.3, the horizontal intensity at this point being 0.082 of a C. G. S. unit. The total length of the cruise was 9,560 miles, the average day's run being 114 miles.

As evidence of the promptness with which the results of the magnetic observations obtained on board the *Carnegie* may be made known, the following facts are cited: The values of the magnetic declination (the variation of the compass, as the mariners call it) obtained on the portion of the cruise from Long Island Sound to Hammerfest, June 10 to July 2, 1914, were printed in the number of the Journal of Terrestrial Magnetism and Atmospheric Electricity which was issued on September 1, 1914; the values observed from Hammerfest to Reykjavik, July 26 to August 23, 1914, were received at Washington on September 21, and those from Reykjavik to Greenport, September 15 to October 11, on October 16. The values of the other magnetic elements (inclination and intensity) were received at Washington at the same time as the declination values.

In general it was found that, for nearly the entire cruise from Long Island Sound to Hammerfest, and thence to Reykjavik, the chart values of west compass-direction were too low, as compared with the values observed aboard the *Carnegie*, by amounts reaching nearly 4° for one chart. The general result found on this cruise was thus in entire agreement with that announced for the first cruise of the *Carnegie*, New York to Falmouth, England, in 1909.

As in previous cruises, much interest was shown in the work of the *Carnegie*, and many courtesies were extended at the ports visited. (For abstracts of log and summary, see pp. 348–349.)

CRUISE IV, MARCH 1915 TO SEPTEMBER 1916.

After the completion of Cruise III, the *Carnegie* was out of commission for a few months, during which time an observatory was built, just abaft the after dome, for the housing of the new instruments used in the measurements of the electrical state of the atmosphere. An additional stateroom on the starboard side of the cabin was provided for the accommodation of an extra observer. The bottom of the vessel was sheathed with a copper alloy, for tropical waters, and a belt, consisting of brass plates, was added to afford some protection against the ice conditions likely to be encountered on the forthcoming cruise. The alterations were made at Hoboken by Tietjen and Lang, according to plans and specifications of the naval architect, H. J. Gielow, of New York, under the immediate supervision of J. P. Ault, as representative of the Department of Terrestrial Magnetism. These improvements were satisfactorily completed by February 17, 1915, on which day the *Carnegie* returned to her berth in Beard's Yacht Basin, at Brooklyn, to be put in commission. While the above work (Pl. 17, Fig. 1) was being done the magnetic instruments were examined, repaired, or altered in the Department shop as required for Cruise IV, and their constants were redetermined.

After a final inspection of the vessel by the Director and W. J. Peters, the *Carnegie*, on March 6, left Brooklyn, under J. P. Ault's command, for Gardiners Bay, where she was successfully swung on March 7 and 8, preparatory to putting to sea. This was the *Carnegie's* fifth visit to Gardiners Bay for the purpose of swinging ship. The result of these swings, made in 1909, 1910, 1913, 1914, and 1915, confirm the existence of local magnetic disturbance in Gardiners Bay and furnish the desired control on the accuracy of the magnetic work aboard the *Carnegie*. W. F. G. Swann remained on board to the last moment to complete the installations and tests of the new atmospheric-electric instruments which had been constructed in the Department shop for this cruise, in accordance with his suggestions. In this work he was assisted by S. J. Mauchly and H. F. Johnston.

The *Carnegie* sailed from Gardiners Bay on March 9, bound for Colon, Panama, the ship's personnel being as follows: J. P. Ault, magnetician and in command of the vessel; H. M. W. Edmonds, magnetician and surgeon, and second in command; H. F. Johnston, I. A. Luke, and H. E. Sawyer (who joined the vessel at Colon), observers; N. Meisenhelter, meteorological observer and clerk; R. P. Doran, first watch officer; M. G. R. Savary, engineer; second and third watch officers, 1 mechanic, 8 seamen, 2 cooks, and 2 cabin boys; 23 persons in all. In addition, S. J. Mauchly remained with the vessel until Panama was reached, to perfect the installation and operation of the newly constructed atmospheric-electric instruments. (On arrival of the *Carnegie* at Lyttelton in November 1915, Observer Loring took the place of H. E. Sawyer, who was assigned to land magnetic work in Africa. When the vessel, furthermore, returned to Lyttelton from the sub-Antarctic cruise, Observer B. Jones joined the vessel in April 1916 in place of H. F. Johnston, assigned to land magnetic work. A. Beech succeeded R. P. Doran as first watch officer in April 1916.)

The passage to Colon was made in about 16 days, during which observations of at least one magnetic element, and usually of all three, were made on every day of the stormy passage. Two deaths from sickness occurred during this passage, namely, A. H. Sorensen, cook, March 11, and W. Stevens, cabin boy, March 24. At Colon the ship instruments were compared with the land instruments, and a new repeat station was established. Unfortunately the previously occupied stations in the vicinity of Colon are now magnetically affected by the large construction operations. On April 4 the *Carnegie* dragged both anchors in a fierce norther, but finally the anchors held. She was subsequently towed to a pier by the tug *Porto Bello* and the dredge *Caribbean*. (For view of shore work, see Pl. 19, Fig. 4.)

The *Carnegie* was next taken through the canal and then she set sail in the Pacific Ocean on April 12 from Balboa, bound for Honolulu. After 39 days at sea, during which 73 determinations were made of the magnetic declination and 39 each of dip and intensity,

including a swing of the ship, the *Carnegie* reported her arrival at Honolulu on May 21. An elaborate scheme of comparisons was carried out between the ship's magnetic instruments and those of the Honolulu Magnetic Observatory, operated by the United States Coast and Geodetic Survey, by which a correlation with other magnetic observatories and standards was effected. Every facility for carrying out these comparisons at the observatory was rendered by the observer-in-charge, W. W. Merrymon. On June 29 and July 3 the *Carnegie* was swung off Pearl Harbor, in about the same locality as that of the *Galilee's* swing of 1907. The results confirm the large differences which had been indicated by the *Galilee* swing, between the values of the magnetic elements at the place of swing and at the observatory, and they also give a means of supplying an additional determination of the constant A of the deviation formula for the *Galilee* at Honolulu. The place of swing can not be surrounded by land stations and hence can not be controlled by land observations. This shows another advantage of a non-magnetic vessel over a vessel with deviations in a magnetic survey of the oceans. After all the labor of planning, observing, and swinging ship, and the tedious computations of the deviation parameters for a vessel having deviations, one is confronted with the fact that hardly one of the few values of A which can be observed during a cruise is wholly above the suspicion of being affected by local disturbance. One can only hope that the effect is neutralized in the mean of a number of observations at the ports available. (For view showing observations at Honolulu Observatory, see Pl. 17, Fig. 4.)

On July 20, 1915, the *Carnegie* reached Dutch Harbor, having sighted the Bogosloff Islands. The commander's report on the sighting of these islands reads:

> "The Bogosloff Islands were seen at a distance of 3 miles at 2 a. m., July 20. There are two islands at present, the eastern one terminating in two high twin peaks with sharp points at the top, the western one having one high mountain with a broad top."

When the *Carnegie* arrived at Dutch Harbor she had already covered 10,158 nautical miles of her present cruise, in 73 days of sailing, at an average of 139 miles per day. During this period 101 values of the magnetic declination and 56 each of inclination and intensity were observed at sea; besides an elaborate program of observations in atmospheric electricity was carried out. Observations for determination of the amount of atmospheric refraction have been continued, as also the usual meteorological observations.

The magnetic declinations observed on the *Carnegie* from Brooklyn to Dutch Harbor, March–July 1915, showed that there had been a steady improvement in the nautical charts since the data obtained during the previous cruises of the *Galilee* and *Carnegie* had become available to hydrographic bureaus. The chart corrections reached a maximum value of about 1°.5 in the region of the Pacific, between Panama and Honolulu, not previously covered by these vessels.

August 5, 1915, the *Carnegie* started on her long continuous passage to Lyttelton, New Zealand. Heavy weather was encountered immediately, and it was impossible to swing ship until August 15, just before leaving the Bering Sea. The farthest north was 59° 33′. The 180th meridian was crossed on August 13, the date August 14, 1915, being omitted. After clearing the Aleutian Islands, the course followed was south practically along the 165th meridian to New Zealand. On September 6 a terrific hurricane from the southwest was encountered. It was necessary to take in all sail and run before the storm, and for 17 hours a speed of 9 knots was made under bare poles. The vessel stood the strain well, but everything was wet on board, the hurricane driving the rain into every crack and opening. Wake Island was passed in the morning of September 12. After passing the first of the Marshall Islands, it was deemed best to keep pretty well to the east on account of prevailing easterly winds and westerly set of the currents. It was necessary to pass well to the westward of the Santa Cruz-Solomon Islands passage while near the equator, but favorable conditions made it possible to weather the Solomon Islands, the engine operating during calms.

After passing the Solomon Islands the *Carnegie* was driven to the westward by the prevailing southeast winds and had to tack twice to avoid the Indispensable Reefs. These reefs were passed October 12, and all the islands and reefs in the Coral Sea were safely cleared. As the Coral Sea was entered, the winds drew somewhat more to the southward, making it necessary to near the Australian Coast off Brisbane. Good winds were blowing across the Tasman Sea, and the light on South Island, New Zealand, east entrance to Foveaux Strait, was made early in the morning of October 31. On account of the slow trip, it was decided to pass through the strait; just before clearing the east end of the strait at sunset, the wind shifted to the southeast, making it necessary to use the auxiliary power. Fortunately, the engine was in good condition and enough coal was reserved for such an emergency. Again, in trying to round Banks Peninsula to enter Port Lyttelton, the wind shifted ahead. With the engine and fore-and-aft sails, however, it was possible to tack to advantage against the wind, thus saving a delay of a day or more in entering port. On November 3 the *Carnegie* entered the harbor at Lyttelton.

Upon only one occasion during the trip did the engine fail to operate, and the cause for this failure was definitely placed. It has proved its value on several occasions and has run well. During the cruise, various and unusual currents were noted. The winds encountered were light and baffling; very rarely were the yards braced square for a fair wind. The total number of miles on the passage, Dutch Harbor to Lyttelton, was 8,865, giving an average of 100 miles per day for 89 days.

Local magnetic disturbances were noted on September 18 near Marshall Islands, October 15 west of Chesterfield Reefs and Islets, October 20 and 21 near the coast of Australia, and October 31 in Foveaux Strait. The aurora australis was seen on the nights of November 1 and 2, consisting of long beams of white light projected vertically from the southern half of the horizon.

Lyttelton was reached with over 6 tons of coal remaining in the bunkers, 40 gallons of kerosene, and 600 gallons of water. It was not necessary to issue a restricted quantity of water per day to each man, as all did their best to economize in the use of fresh water. A salt-water shower bath, connected with the deck pump, was in position ready for use at all times. The health of the party was good during the entire trip.

A stay of 33 days at Lyttelton was necessary for the completion of the observational work and comparisons at the Christchurch Magnetic Observatory and for the overhauling and outfitting of the vessel. During this stay at Lyttelton, as also during the subsequent one, the work of the *Carnegie* was facilitated by certain officials, and by Professors Farr and Chilton, of Canterbury College, and Director Skey, of Christchurch Observatory (Pl. 19, Fig. 5).

December 6 the *Carnegie* left Lyttelton for a sub-Antarctic circumnavigation cruise. The 180th meridian was crossed on December 9, so that date was repeated as December 9 (2). The vessel arrived at King Edward Cove, South Georgia, on January 12, 1916, going the last 24 hours under her own auxiliary power. She again sailed on the 14th, being towed out of harbor against a heavy head wind by the steam whaler *Fortuna*. Icebergs became more numerous and fog was almost continuous. However, January 18 was the only day on the entire trip in southern waters on which it was impossible to obtain observations for the magnetic declination. On January 22 the vessel passed along the north coast of Lindsay Island about 3 miles offshore. The *Carnegie's* track of 1911 to the westward of Australia was twice intersected for the determination of secular change. Lyttelton was reached on April 1, 1916. This sub-Antarctic cruise, accomplished as far as known for the first time in a single season, was made practically between the parallels of 50° and 60° south until the neighborhood of Australia was approached, when it became necessary, on two occasions, to cross somewhat north of the 50th parallel. Its aggregate length was 17,084 nautical miles, the time of passage 118 days, and the average day's run 145 miles. For a more complete account of this passage, see J. P. Ault's report, pp. 326–330; also views on Plate 18.

After a stay of nearly 7 weeks, the *Carnegie* again left Lyttelton (Pl. 17, Fig. 5) for the last time on this cruise, being towed out to sea on May 17 by the tugboat *Lyttelton*. Light head winds and calms were encountered, so the engine was started to gain an offing, running all night. For five days the wind held northeast, forcing the vessel well toward the Chatham Islands. May 22 was repeated, on crossing the 180th meridian. On May 23 favorable winds were encountered for the first time, and for three days fair winds were enjoyed. Then northerly winds and calms made it necessary for the course to be taken westward near the Kermadec Islands. On June 1 the wind was again favorable, but thereafter until arrival at Pago Pago, it was necessary to sail close-hauled, with northeast to northwest winds. Landfall was made with some difficulty on account of the heavy clouds and squalls hanging over the island. Observations were carried out as usual during the passage. No magnetic-declination observations were obtained on May 30 and June 4 on account of clouds. Considerable lightning and thunder attended the squally weather. The new gooseneck on the upper topsail yard carried away on May 27, and was replaced with the extra one ordered at Lyttelton. The engine was operated to get offshore when leaving Lyttelton, to clear Savage Island during a calm on June 4, and to enter the harbor of Pago Pago on June 7. The time of passage was 22 days, with a daily run of 118 miles, for a total of 2,595 miles.

The shore observations having been completed, the *Carnegie* left Pago Pago on June 19, under her own power. The engine operated well, taking the vessel out against a stiff head trade wind. The wind was too strong outside to allow making to windward of Tutuila, so the *Carnegie* went around the west end. The Union Group was weathered, but the wind broke off to the north of east, compelling the vessel to go to leeward of the main Phœnix Group. The wind held north of east, forcing the *Carnegie* considerably to the westward of the route planned; however, the crossings with previous tracks were made at the points desired. No storms or calms were encountered. The hot weather was very trying, but the party, with two or three exceptions, kept well. Magnetic declinations were obtained twice daily, with two exceptions. The average difference, without regard to sign, between the results obtained by the two observers at the collimating compass was 3′ for the 51 determinations. This affords some evidence as to the character of the weather and conditions encountered. Port Apra, Guam, was reached on Monday, July 17, 1916. The total run from Pago Pago was 3,987 miles, giving a daily average of 147 miles for the 27-day trip.

At Port Apra, connection was made with the *Galilee* observations of 1907 and extensive intercomparisons of all instruments were made. The *Carnegie* sailed from Port Apra on August 7, bound for San Francisco. The track followed was arranged to cross as frequently as possible the previous tracks of the *Galilee* and the *Carnegie*, and to obtain additional magnetic data in regions where most needed. For 7 days continuous heavy gales were encountered from the southwest, making it necessary to heave to for 2 days in succession, August 9 and 10. The vessel was thus driven northward and compelled to follow very closely the track of the *Galilee* from Guam to Japan, up to the point where the many tracks intersect (see Plate 20). This was the worst spell of bad weather the *Carnegie* had thus far encountered. After August 17, moderate weather was experienced. There was considerable fog and cloudiness, but, with four exceptions, observations for declination were obtained daily. The engine was operated frequently, for a total of 90 hours, during calms and for swinging ship. On August 26, the vessel was swung for intensity and inclination observations, both helms. On August 27, a declination swing was started, but after 5 headings had been completed clouds prevented further observations. Fog was recorded on 12 days and rain or mist on 34 days.

On September 20, the *Carnegie* was becalmed off the coast of California, so the engine was operated, and after a 24-hour run San Francisco was reached on September 21. Fortu-

nately, Point Reyes was sighted at 1 o'clock in the morning before the fog closed down. Creeping through the fog until the light vessel was heard, a pilot was taken aboard, and the *Carnegie* made the entrance into the harbor through the fog under her own power. The total distance run from Guam was 5,937 miles, the time of passage being 46 days, and the average daily run 129 miles. The chronometers were found in error only 8ˢ7.

The total distance covered on Cruise IV, from March 6, 1915, to September 21, 1916, was 48,626 miles; as the time actually at sea was 375 days, the average day's run was 130 miles. During this period the *Carnegie* reached the extreme latitudes of 59° 33′ N. and 60° 33′ S. For further information regarding this cruise, see abstract of log, pages 350–356.

As heretofore, the *Carnegie's* staff is indebted for special courtesies shown at the ports visited and for valuable assistance rendered by various persons and officials.

METHODS OF WORK ON THE CARNEGIE.

The methods adopted and the principles followed were, in general, the same for the scientific work aboard the *Carnegie* as for the *Galilee* (pp. 14–16). The chief modifications arose from the fact that the *Carnegie* is a non-magnetic ship and from the introduction of certain new and improved instruments.

The *Carnegie* was designed with the view of making it possible to place the various instruments in the most advantageous positions possible, and far enough apart so that the fundamental principle to have each magnetic element determined independently by simultaneous observations with two different instruments, and by different observers, could be carried out successfully. The actual positions of the instruments may be seen from Figure 13, page 202, and Plate 9, Figure 2.

To test the question whether at any of the instrument positions there were magnetic effects attributable to anything aboard the *Carnegie*, the vessel was swung occasionally both in harbor and at sea, and magnetic observations were made on the various headings, as in the case of a magnetic ship like the *Galilee*. The results of these observations will be found tabulated and discussed in the special report (pp. 423 *et seq.*). It will be seen that the conclusion as to the absence of any deviation-corrections large enough to be taken in account is well supported.

There being no troublesome and time-consuming deviation-corrections to determine, the computations and derivation of magnetic data were greatly simplified. The observers reduced their observations and obtained preliminary results of sufficient accuracy for mariners' purposes within an hour after the completion of the observations aboard. Reaching a port, the commander of vessel transmitted an abstract of these results to the Office at Washington, where they were manifolded and promptly transmitted to the chief hydrographic establishments. There are letters on file from some of these establishments to the effect that they were receiving magnetic data from the *Carnegie* more promptly than they could be obtained from their own vessels.

The observation forms were adapted to the new instruments and were modified as experience from time to time suggested. Specimen observations and computations will be found on pages 212–231, also on pages 234, 240, and 243–250.

In order not to expand the present volume unduly, various matters of interest pertaining to methods of observation and to instrumental appliances must be passed over here and treated in a subsequent volume.

the magnet system while sighting on the Sun or star, hence he knows precisely to what part of the arc the stellar azimuth applies. In brief, practically the same method of observation can be used at sea with the marine collimating-compass as on land with a magnetometer. In the latter case the magnetometer circle is set to some convenient point on the magnet scale and then scale readings are taken of the positions of the magnet during the interval of observation. The angle is next determined between the circle setting and some mark, or the true meridian, and the declination is finally deduced. Similarly, with the marine collimating-compass, the angle between the magnet (say, middle of scale) and some celestial body, as the Sun, is read with a sextant to the nearest minute of arc at a given time, and then, with the sextant still clamped at the same angle, simultaneous readings of the Sun's image on magnet scale and of watch are taken. With the aid of the time readings, the motion of the Sun during the interval of observation is taken into account, and the true azimuths determined, whereas the scale readings give the varying positions of the magnet system.

GENERAL FORMULÆ.

In Figure 10, which represents the celestial sphere, stereographically projected upon the plane of the horizon, let Z be the zenith of the magnetic station observed at with the collimating compass; s the star sighted; NS the astronomic meridian; $N'S'$ the mag-

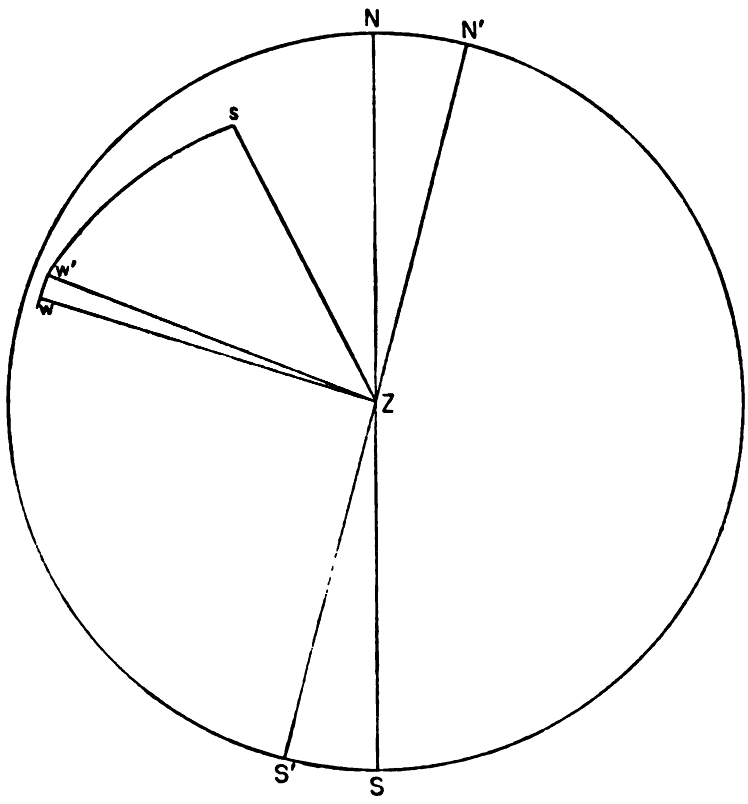


FIG. 10.

netic meridian. Suppose the observer, looking into one of the collimators, sees the scale apparently just above the western horizon. This scale is designated by the letter w. Suppose further that the point of the scale brought into coincidence with the star's image is to the right of the middle scale-division. Now let this point and the middle of the scale be projected to the celestial vault, and then to the plane of the projection, at w' and at w, respectively. The arc measured by the sextant is then projected to sw'.

Let the following notation be adopted:

r = the mean of a number of scale readings.[1]
h = the altitude of the star.
v = the value of one scale division, in degrees.
m = the altitude of the scale, positive above the horizon, negative below.
the angle $SZS' = NZN' = D$, the magnetic declination.
" " $SZs = A_s$, the astronomic azimuth of the star.
" " $S'Zw = A_c$, constant for the scale in question.
" " $wZw' = r - 5$, the mean of a number of scale readings, less 5.
the arc $w's = \Delta$, the arc measured by the sextant, corresponding to r.
" " $sZ = 90° - h$, the apparent zenith distance of the star.
" " $wZ = w'Z = 90° - m$, the apparent zenith distance of the scale.
the angle $w'Zs = A$, the horizontal angle between scale and star.

The magnetic declination may then be expressed by the equation

$$D = A_s - [A_c + (r - 5.00)v \pm A] \tag{1}$$

The terms A_c and v of this equation are constant for each scale of the instrument. The term A is computed from the spherical triangle $w'Zs$, of which the side $w's$ is directly measured, and the sides $w'Z$ and sZ are known from the elevation or depression, m, of the scale, and the apparent altitude, h, of the star. The constants m, A_c, and v are determined at magnetic comparison-stations. The apparent altitude, h, may be observed directly or it may be computed. When obtained by observation at sea, it is to be freed from dip of the horizon, but if the true altitude is computed, it is to be increased by the corresponding refraction correction.

The angle A, or the azimuthal difference between the scale and star, has been given a double sign in equation (1) since the star may be to the right (+) or left (−) of the scale. It may be computed from any one of the following fundamental formulæ of spherical trigonometry, in which m may be either positive or negative:

$$\cos\frac{1}{2}A = \sqrt{\cos(s-\Delta)\cos s \sec h \sec m}$$

$$\sin\frac{1}{2}A = \sqrt{\sin(s-m)\sin(s-h)\sec h \sec m}$$

$$\tan\frac{1}{2}A = \sqrt{\sin(s-m)\sin(s-h)\sec(s-\Delta)\sec s}$$

$$\cos A = \frac{\cos\Delta - \sin h \sin m}{\cos h \cos m} \tag{2}$$

In the above equations, $2s = \Delta + m + h$. If $m = 0$, they reduce to

$$\cos\frac{1}{2}A = \sqrt{\cos\frac{1}{2}(h-\Delta)\cos\frac{1}{2}(h+\Delta)\sec h}$$

$$\sin\frac{1}{2}A = \sqrt{\sin\frac{1}{2}(\Delta-h)\sin\frac{1}{2}(\Delta+h)\sec h}$$

$$\tan\frac{1}{2}A = \sqrt{\tan\frac{1}{2}(\Delta-h)\tan\frac{1}{2}(\Delta+h)}$$

$$\cos A = \cos\Delta \sec h \tag{3}$$

Equation (3) is convenient for logarithmic computation, and though the angle is given by its cosine, it is sufficiently accurate for five-place logarithms, when A is over 30°, and the

[1]The scale divisions are mentally numbered from left to right, the middle division being 5.

result is required within 0°.02 only. If m is not zero, but less than 1°, then the arc can be substituted for its sine, and its cosine can be taken as unity, and (2) may be written

$$\cos A = \cos \Delta \sec h - m \tan h$$

Assuming $\cos A' = \cos \Delta \sec h$, we get

$$\cos A' - \cos A = -2 \sin \frac{1}{2}(A' + A) \sin \frac{1}{2}(A' - A) = m \tan h.$$

When $A' - A$ is less than 2°, the arc may be substituted for its sine, and

$$A' - A = -m \tan h \operatorname{cosec} \frac{1}{2}(A' + A)$$

This equation will give $A'-A$ by a series of rapid approximations, each one furnishing a new and closer value of A'.

If Δ and A are nearly equal, it will be expedient to determine the angle A in another way, by computing and tabulating the small angle $\Delta - A$, as follows: (2) may be written

$$\cos \Delta = \sin h \sin m + \cos h \cos m \cos A$$

and we also have

$$\sin m = m - \frac{m^3}{6} + \text{etc.} \qquad \cos m = 1 - \frac{m^2}{2} + \frac{m^4}{24} - \text{etc.}$$

Let us assume

$$A = \Delta - x \tag{4}$$

From (4) we obtain

$$\cos A = \cos (\Delta - x) = \cos \Delta + x \sin \Delta - \frac{x^2}{2} \cos \Delta - \frac{x^3}{6} \sin \Delta + \text{etc.}$$

Substituting the expressions for $\sin m$, $\cos m$, and $\cos A$ in the equation for $\cos \Delta$, we have

$$\cos \Delta = \begin{cases} + m \sin h - \dfrac{m^3}{6} \sin h + \text{etc.} \\ + \cos h \cos \Delta + x \cos h \sin \Delta - \dfrac{x^2}{2} \cos h \cos \Delta - \dfrac{x^3}{6} \cos h \sin \Delta + \text{etc.} \\ - \dfrac{m^2}{2} \cos h \cos \Delta - \dfrac{xm^2}{4} \cos h \sin \Delta + \dfrac{x^2 m^2}{4} \cos h \cos \Delta + \text{etc.} \end{cases}$$

and from these we obtain the following general expression for x:

$$x = \begin{cases} - m \tan h \operatorname{cosec} \Delta + \dfrac{m^3}{6} \tan h \operatorname{cosec} \Delta - \text{etc.} \\ + \cot \Delta (\sec h - 1) + \dfrac{x^2}{2} \cot \Delta + \dfrac{x^3}{6} - \text{etc.} \\ + \dfrac{m^2}{2} \cot \Delta + \dfrac{xm^2}{2} - \text{etc.} \end{cases}$$

When weather conditions permit in actual work, the Sun is taken so low that $\Delta - A$ rarely exceeds 1°.5. Usually m should be even smaller; so, in general, the series for x is rapidly convergent. Let m and x be expressed hereafter in degrees; then we have

$$x = \begin{cases} - m \tan h \operatorname{cosec} \Delta + 0.00005\, m^3 \tan h \operatorname{cosec} \Delta - \text{etc.} \\ + 57.3 \cot \Delta (\sec h - 1) + 0.00872\, x^2 \cot \Delta + 0.00005\, x^3 - \text{etc.} \\ + 0.00872\, m^2 \cot \Delta + 0.00015\, x\, m^2 - \text{etc.} \end{cases} \tag{5}$$

The two principal terms of this expression give an approximate value of x, which may be used in calculating the subsequent terms, if desired. Ordinarily, this first approximation suffices, and equation (4) then reduces to

$$A = \Delta - 57.3 \cot \Delta (\sec h - 1) + m \tan h \operatorname{cosec} \Delta$$

Consider separately the two parts

$$-\ 57.3 \cot \Delta\ (\sec h - 1), \text{ and } +\ m \tan h \operatorname{cosec} \Delta$$

The first is a reduction to the sextant angle Δ, which converts it approximately into the corresponding horizontal angle. It may be observed that this reduction changes sign as Δ passes from the first to the second quadrant, and referring to the above equation, it may be seen that when Δ is less than (greater than) 90°, the reduction to apply to Δ in order to get A must decrease (increase) the sextant angle Δ. The second part is a reduction to the measured angle Δ, due to the inclination of the collimator to the horizon. Referring again to the above equation, we see that an elevated (depressed) scale requires that the value of the sextant angle Δ be increased (decreased) to get A.

Introducing these reductions in (1), we have finally the approximate working formula

$$D = A_s - \{A_c + (r - 5.00)\ v \pm [\Delta - 57.3 \cot \Delta\ (\sec h - 1) + m \tan h \operatorname{cosec} \Delta]\} \quad (6)$$

Here the upper sign is used for sextant in normal position, and the lower for inverted position; that is, for a star to the right and left of the scale, respectively. To facilitate the application of this formula, Tables 46 and 47 (pp. 182 and 183) have been prepared. The last two terms may be obtained, one directly from Table 46, the other by the aid of Table 47, which contains the product of two of the factors, $\tan h$ and $\operatorname{cosec} \Delta$.

In order to investigate the accuracy of equation (5), when terms of higher orders are omitted, let it be assumed that a precision in the final result of 0°02 is sufficient, since this is closer than the magnetic declination can be determined at sea. For values of h not greater than 45°, and values of Δ not less than 45°, the effect of the third-order terms on x can never be greater than 0°02, if x and m do not exceed 4°0. By reference to Table 46, it will be seen that under favorable weather conditions, admitting of Sun observations at low altitudes, the value of x may be restricted to much less than 4°0 by a judicious selection of scales. In a well-constructed instrument the inclination, m, of the collimators should not exceed 1°0. Hence terms of the third and higher orders can usually be omitted.

A preliminary value of the argument x is obtained from Tables 46 and 47, and values of terms of the second order may then be taken out of Table 48.

To illustrate the use of Tables 46, 47, and 48 and also the mutual dependence of algebraic signs, the following hypothetical example is given. The values of m are made extraordinarily large in order to introduce terms of the second order.

$m =$	+ 2°0	− 2°0	+ 2°0	−2°0
$h =$	14.0	14.0	14.0	14.0
$\Delta =$	119.0	119.0	61.0	61.0
From Table 46	+ 0.972	+ 0.972	− 0.972	−0.972
Factor from Table 47 multiplied by m	+ 0.570	− 0.570	+ 0.570	−0.570
From Table 48 for m	+ 0.019	+ 0.019	− 0.019	−0.019
Table 48 for x = (±0°97 ± 0°57 ± 0°02, etc)	+ 0.012	.000	.000	− 0.012
$A =$	120.57	119.42	60.58	59.43

Equation (2), differentiated with respect to Δ, gives

$$dA = \frac{\sin \Delta}{\cos h \cos m \sin A}\, d\Delta$$

From this and equation (1) it is evident that, for the same values of A, the influence of an error in the measured angle Δ has the least effect on the magnetic declination when the star is low. A low altitude is a desideratum not peculiar to this method alone, but also to any method of astronomically determining an azimuth from a single star. With usual compass-devices consisting of mirror combinations, the error increases with the altitude

TABLE 46.—*Values of First-Order Term, 57.3 cot Δ (sec h−1).*

TABLE 47.—*Correction Factor for Elevated or Depressed Scale, tan h cosec Δ.*

Δ	h = 0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15° = h	Δ
°																	°
90	0.000	0.017	0.035	0.052	0.070	0.087	0.105	0.123	0.141	0.158	0.176	0.194	0.213	0.231	0.249	0.268	90
85	.000	.018	.035	.053	.070	.088	.106	.123	.141	.159	.177	.195	.213	.232	.250	.269	95
80	.000	.018	.035	.053	.071	.089	.107	.125	.143	.161	.179	.197	.216	.234	.253	.272	100
75	.000	.018	.036	.054	.072	.091	.109	.127	.145	.164	.183	.201	.220	.239	.258	.277	105
70	.000	.019	.037	.056	.074	.093	.112	.131	.150	.169	.188	.207	.226	.246	.265	.285	110
65	.000	.019	.039	.058	.077	.097	.116	.135	.155	.175	.195	.214	.235	.255	.275	.296	115
60	.000	.020	.040	.061	.081	.101	.121	.142	.162	.183	.204	.224	.245	.267	.288	.309	120
55	.000	.021	.043	.064	.085	.107	.128	.150	.172	.193	.215	.237	.259	.282	.304	.327	125
50	.000	.023	.046	.068	.091	.114	.137	.160	.183	.207	.230	.254	.277	.301	.325	.350	130
45	.000	.025	.049	.074	.099	.124	.149	.174	.199	.224	.249	.275	.301	.326	.353	.379	135
40	.000	.027	.054	.082	.109	.136	.164	.191	.219	.246	.274	.302	.331	.359	.388	.417	140
35	.000	.030	.061	.091	.122	.153	.183	.214	.245	.276	.307	.339	.371	.403	.435	.467	145
30	.000	.035	.070	.105	.140	.175	.210	.246	.281	.317	.353	.389	.425	.462	.499	.536	150

TABLE 48.—*Values of Second-Order Terms, 0.00872 x^2 cot Δ, or 0.00872 m^2 cot Δ.*

x or m	Δ = 30°	35°	40°	45°	50°	55°	60°	65°	70°	75° = Δ	x or m
°	°	°	°	°	°	°	°	°	°	°	°
0.6	0.005	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.6
0.7	.007	0.006	0.005	.....	.....	.....	.....	.....	.....	.....	0.7
0.8	.010	.008	.007	0.006	0.005	.....	.....	.....	.....	.....	0.8
0.9	.012	.010	.008	.007	.006	0.005	.....	.....	.....	.....	0.9
1.0	.015	.012	.010	.009	.007	.006	0.005	.....	.....	.....	1.0
1.1	.018	.015	.013	.011	.009	.007	.006	0.005	.....	.....	1.1
1.2	.022	.018	.015	.013	.011	.009	.007	.006	0.005	.....	1.2
1.3	.026	.021	.018	.015	.012	.010	.009	.007	.005	.....	1.3
1.4	.030	.024	.020	.017	.014	.012	.010	.008	.006	0.005	1.4
1.5	.034	.028	.023	.020	.016	.014	.011	.009	.007	.005	1.5
1.6	.039	.032	.027	.022	.019	.016	.013	.010	.008	.006	1.6
1.7	.044	.036	.030	.025	.021	.018	.015	.012	.009	.007	1.7
1.8	.049	.040	.034	.028	.024	.020	.016	.013	.010	.008	1.8
1.9	.055	.045	.038	.031	.026	.022	.018	.015	.011	.008	1.9
2.0	.060	.050	.042	.035	.029	.024	.020	.016	.013	.009	2.0

in a greater ratio than sec h. The azimuth of the star, moreover, depends on the computed local time, which is subject to errors of the ship's run. If A_s, δ, q, and h represent the azimuth, declination, parallactic angle, and altitude of the star, respectively, for the hour angle t, at the instant of observation for magnetic declination, we have the well-known differential formula of spherical astronomy,

$$dA_s = \frac{\cos \delta \cos q}{\cos h} dt$$

from which it is likewise evident that the influence of an error in time on the azimuth is a minimum, as far as the altitude is concerned, when the star is in the horizon. If the altitudes are measured simultaneously with the magnetic-declination observations, an excellent check on the azimuth is available through the equation

$$\cos \frac{1}{2} A = \sqrt{\cos s \cos (s - p) \sec \varphi \sec h}$$

in which φ and p denote the latitude and polar distance respectively, and $s = \frac{1}{2}(h + p + \varphi)$. The azimuth obtained from this formula is independent of the local time, and is affected only by refraction errors in the low altitude, and by errors in the assumed latitude.

INSTRUMENTAL CONSTANTS.

In a perfect instrument the axes of the four collimators would lie, two in the vertical plane of the magnetic meridian and two in the vertical plane at right angles to it; and all four would be in the plane of the horizon. There are mechanical difficulties, however, which prevent the exact realization of these requirements, and even if the instrument were found to be in perfect adjustment, it is questionable whether it would remain so.

The determination of all the constants may be made with a non-magnetic theodolite, at a station where the exact magnetic declination is known during the operation, together with an approximate value of the vertical intensity. Usually at such a station the astronomic azimuth of some mark is known. This mark may be used as the reference point for each scale, provided it is in, or nearly in, the direction of one of the inter-cardinal points, in which case it may be seen, unobstructed by the compass bowl, from any of the four positions occupied by the theodolite in front of the four scales. If the view of the mark is obstructed by the bowl, another must be selected.

The compass is mounted on its tripod and oriented fully 5 minutes before observations. The theodolite is set up on the arm of the compass tripod, placed before the selected scale, leveled, and adjusted to sidereal focus (see Pl. 11, Fig. 7); it is then pointed upon the middle division of the scale, with horizontal thread just touching the tops of the shorter divisions. If the telescope now points symmetrically through the window, the arm is firmly clamped, the bowl is gently drummed, and the observations begin. Otherwise the arm must be shifted for a lateral adjustment and all the footscrews turned to produce a vertical adjustment as required.

The constants, A_e and m, for each scale may be determined from the same observations. Observations begin with readings on the mark, theodolite direct, or vertical circle right, followed by a pointing on each visible division of the scale, and a reversal of the procedure with vertical circle left. In the middle of the operation it will be convenient to determine m by pointing on the tops of the shorter divisions and reading the vertical circle, both left and right.

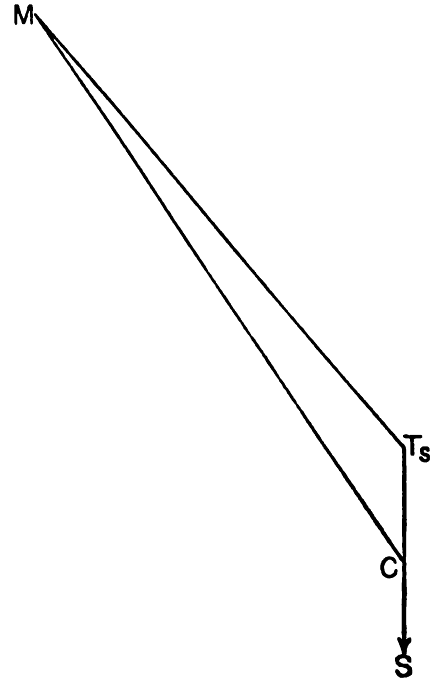


FIG. 11.

Reduction to center.—If there is an appreciable ratio between the distances compass-theodolite and compass-mark, then the angles measured by the theodolite must be reduced to the compass center. In Figure 11 the relative positions, in plan, of compass, theodolite, and mark are shown at C, T_s, and M, respectively. The theodolite is in position to determine the constants of scale S. The line CS represents the direction of "scale south," or approximately the magnetic meridian. Let

$T_sC = d =$ the distance of the theodolite from the compass.

$CM = D =$ the distance of the mark.

$ST_sM =$ the angle measured by the theodolite, always obtained by taking the scale reading from the mark reading.

$c' =$ the correction to this angle, in minutes of arc, to reduce it to the compass center, always algebraically additive to ST_sM.

$SCM =$ the angle required at the compass center.

Then by the formula for reduction to center,

$$c' = \frac{d \sin ST_sM}{D \sin 1'} \tag{7}$$

For the determination of the constants of marine collimating-compass 1 (C1), the theodolite is mounted on an arm which may be turned about the vertical axis of the compass (see Pl. 11, Fig. 7). The distance, $d = 28.1$ cm., is therefore constant for this particular arrangement. If this value be introduced in equation (7), and if D be expressed in kilometers, the above equation becomes

$$c' = \frac{0.97 \sin ST_cM}{D}$$

It is readily seen that the formula is general, and applies to any scale with the mark in any quadrant, and in general the correction is numerically the same with opposite signs for opposite scales.

A specimen of observation and calculation of the constants, A_c and m, determined at Suva Vou, Fiji, June 15, 1912, for scale south and for scale west, is given on page 186. (For a view of shore observations, see Pl. 11, Fig. 7.) The observations were made at station A simultaneously with the magnetometer observations at station B. The resulting values are

$$m = -1°.11 \text{ and } A_{cs} = +\ 0°.35, \text{ for scale south;}$$
$$m = +0°.59 \text{ and } A_{cw} = +90°.78, \text{ for scale west.}$$

Adjustment of A_c.—Where the horizontal angles between adjacent scales have been determined independently of the magnetic declination or of the magnetic direction of each scale, by simultaneous readings of the two scales with two theodolites which have been collimated one upon the other, then the individual determinations of A_c for each scale serve to determine the A_c for all the other scales. The values of A_c for *each* scale can then be made to depend upon *all* the observations of A_c for the four scales.

Before proceeding to this adjustment, which, by the method of least squares, finally leads to very simple expressions, let us first consider the adjustment of the horizontal angles between adjacent scales when measured with two theodolites, as above explained.

Let R^I, R^{II}, R^{III}, R^{IV}, be the most probable values of the angles between the scales E, N, W, and S, so that the measurements give:

$$\begin{aligned}
R^I_o + v^I &= A_{ce} - A_{cn} + v^I = R^I \text{ with weight } p^I\\
R^{II}_o + v^{II} &= A_{cn} - A_{cw} + v^{II} = R^{II} \text{ with weight } p^{II}\\
R^{III}_o + v^{III} &= A_{cw} - A_{cs} + v^{III} = R^{III} \text{ with weight } p^{III}\\
R^{IV}_o + v^{IV} &= A_{cs} - A_{ce} + v^{IV} = R^{IV} \text{ with weight } p^{IV}
\end{aligned}$$

We have the condition equation

$$360° - (R^I_o + R^{II}_o + R^{III}_o + R^{IV}) = v^I + v^{II} + v^{III} + v^{IV}$$

The one correlate, C_1, is given by

$$C_1 = \frac{360° - (R^I_o + R^{II}_o + R^{III}_o + R^{IV}_o)}{\Sigma \frac{1}{p}}$$

and

$$v^I = \frac{1}{p^I} C_1 \qquad v^{II} = \frac{1}{p^{II}} C_1 \qquad v^{III} = \frac{1}{p^{III}} C_1 \qquad v^{IV} = \frac{1}{p^{IV}} C_1$$

which are the most probable corrections to R^I_o, R^{II}_o, R^{III}_o, R^{IV}_o, respectively.

If $p^I = p^{II} = p^{III} = p^{IV}$, then

$$v^I = v^{II} = v^{III} = v^{IV} = \frac{1}{4}[360° - (R^I_o + R^{II}_o + R^{III}_o + R^{IV}_o)]$$

The angles R^I, R^{II}, R^{III}, R^{IV} remain constant if no structural changes take place in the optical systems, but the constants A_{ce}, A_{cw}, A_{cn}, and A_{cs} are subject, each equally, to changes that may occur in the direction of the magnetic axis of the system of parallel magnets.

Determination of Constants for Marine Collimating-Compass, C1

Station: Suva Vou
Theodolite: 5
Chron'r: 256

Date: June 15, 1912
Magn'r: 4 at sta. *B*

Obs'r: H. M. W. E.
Rec'd'r: W. J. P.

I. Scale South

Horizontal Circle

	Ver. A			B		Means	
	°	'	"	'	"	°	'
Scale Div. 4, Ver. Cir. R	359	04	50	05	00	359	04.9
" " 5, " " R	360	02	40	03	00	360	02.8
" " 6, " " R	361	01	10	01	10	361	01.2
" " 6, " " L	181	02	20	02	10	181	02.2
" " 5, " " L	180	03	20	03	30	180	03.4
" " 4, " " L	179	04	40	04	20	179	04.5
Mean Scale	....			....		0	03.2
Mark, Ver. Cir. R	315	47	20	47	20	315	47.3
" " " L	135	47	00	47	20		47.2

Mean Mark Reading	315	47.2
Mark less Mean Scale	315	44.0
Reduction to Center		−0.2
Reduced Angle = *a*	315	43.8
Astronomic Azimuth of Mark	326	27.8
Magnetic Declination (*D*)	+10	22.8
Magnetic Azimuth of Mark = *b*	316	05.0
$A_s = b - a$		+21.2
	(+0°.35)	

Vertical Circle

Ver. A			B		Means	
°	'	"	'	"	°	'
178	59	50	59	00	−1	00.6
1	13	00	11	30	−1	12.2
				m =	−1	06.4
				=	(−1°.11)	

Time

	h	*m*
Beginning	10	24
Ending		33
Mean	10	28
Corr'n 256 on L. M. T.		−12
Local mean time	10	16

Remarks

Mark distant, 3 km.
D at *A* by Stand., +10° 22'.8
Instrument drummed
Window 1

II. Scale West

Horizontal Circle

	Ver. A			B		Means	
	°	'	"	'	"	°	'
Scale Div. 4, Ver. Cir. R	89	25	00	25	20	89	25.2
" " 5, " " R	90	26	50	27	00	90	26.9
" " 6, " " R	91	29	30	29	40	91	29.6
" " 6, " " L	271	30	30	30	30	271	30.5
" " 5, " " L	270	29	00	29	20	270	29.2
" " 4, " " L	269	27	00	27	00	269	27.0
Mean Scale	....			....		90	28.1
Mark, Ver. Cir. R	315	47	10	47	00	315	47.1
" " " L	135	46	30	47	00		46.8

Mean Mark Reading	315	46.9
Mark less Mean Scale	225	18.8
Reduction to Center		−0.2
Reduced Angle = *a*	225	18.6
Astronomic Azimuth of Mark	326	27.8
Magnetic Declination (*D*)	+10	22.2
Magnetic Azimuth of Mark = *b*	316	05.6
$A_{sw} = b - a$	+90	47.0
	(+90°.78)	

Vertical Circle

Ver. A			B		Means	
°	'	"	'	"	°	'
180	48	00	48	00	+0	48.0
359	37	30	36	00	+0	23.2
				m =	+0	35.6
				=	(+0°.59)	

Time

	h	*m*
Beginning	10	46
Ending		56
Mean	10	51
Corr'n 256 on L. M. T		−12
Local mean time	10	39

Remarks

Mark distant, 3 km.
D at *A* by Stand., +10° 22'.2
Instrument drummed
Window 2

Let v^I, v^{II}, v^{III}, and v^{IV} be the most probable corrections to the independently observed values A_{ss}, A_{sw}, A_{sn}, and A_{se}, respectively, of the scale constants. Placing

$$A_{se} - A_{sn} - R^I = n^I \qquad A_{sn} - A_{sw} - R^{II} = n^{II} \qquad A_{sw} - A_{ss} - R^{III} = n^{III}$$

the equations of condition are

$$v^{IV} - v^{III} + n^I = 0 \qquad v^{III} - v^{II} + n^{II} = 0 \qquad v^{II} - v^I + n^{III} = 0$$

Assigning to A_{se} one-half the weight of the others, since "scale east" for this particular instrument is slightly out of focus, the adjustment gives

$$v^I = +0.143\, n^I + 0.429\, n^{II} + 0.714\, n^{III} \qquad v^{III} = +0.143\, n^I - 0.571\, n^{II} - 0.286\, n^{III}$$
$$v^{II} = +0.143\, n^I + 0.429\, n^{II} - 0.286\, n^{III} \qquad v^{IV} = -0.857\, n^I - 0.571\, n^{II} - 0.286\, n^{III}$$

The numerical coefficients of n^I, n^{II}, n^{III} will always be the same for the above assigned system of weights.

When equal weights are assigned to the four scales, the adjustment gives

$$v^I = +0.25\, n^I + 0.50\, n^{II} + 0.75\, n^{III} \qquad v^{III} = +0.25\, n^I - 0.50\, n^{II} - 0.25\, n^{III}$$
$$v^{II} = +0.25\, n^I + 0.50\, n^{II} - 0.25\, n^{III} \qquad v^{IV} = -0.75\, n^I - 0.50\, n^{II} - 0.25\, n^{III}$$

which are the most probable corrections to the observed values of A_{ss}, A_{sw}, A_{sn}, and A_{se}, on this assumption.

In Table 49 are tabulated the observed values of A_s during the first and second cruises of the *Carnegie* and the adjusted values resulting from taking $R^I = 90°.209$, $R^{II} = 89°.601$, $R^{III} = 90°.339$, and $R^{IV} = 89°.850$. These values of R^I, R^{II}, R^{III}, and R^{IV} were determined at Rio de Janeiro in December 1910, and at Antipolo in February 1912, by using two theodolites. From October 1910 to January 28, 1914, the observers drummed the instrument lightly with the fingers, to overcome the frictional resistance of the pivot.

TABLE 49.—*Observed and Adjusted Values of A_s.*

Date	Station	Observed Values of A_s for Scale				Adjusted Values of A_s for Scale				Remarks
		S	W	N	E	S	W	N	E	
1909		°	°	°	°	°	°	°	°	
Jan. 27	Washington.....	0.40	90.50	180.40	270.36	0.32	90.66	180.26	270.47	
July 26	New York, Bronx	0.38	90.58	180.45	270.49	0.37	90.71	180.31	270.52	
Oct. 25,29	Falmouth......	0.42	90.70	180.48	270.45	0.42	90.76	180.36	270.57	
1910										
Jan. 14,18	Bermuda.......	0.36	90.56	180.36	270.44	0.33	90.67	180.27	270.48	
Mar. 9,10	New York, Bronx	0.41	90.67	180.38	270.46	0.38	90.72	180.32	270.53	
June 13	Greenport......	0.32	90.71	180.36	270.39	0.35	90.69	180.29	270.50	
Aug. 2	Vieques........	0.46	90.76	180.38	270.56	0.44	90.77	180.38	270.58	
Oct. 4	Pinheiro........	0.36	90.63	180.32	270.44	0.34	90.67	180.28	270.48	Instr. drummed.
Dec. 12	Rio de Janeiro ..	0.36	90.66	180.31	270.49	0.35	90.69	180.29	270.50	Do.
1911										
Jan. 24	Pilar...........	0.33	90.64	180.33	270.49	0.34	90.68	180.28	270.49	Do.
Mar. 30	Cape Town.....	0.36	90.68	180.29	270.46	0.34	90.68	180.28	270.49	Do.
June 19	Colombo.......	0.37	90.68	180.29	270.47	0.35	90.69	180.29	270.50	Do.
Nov. 10	Batavia[1]........	0.33	90.67	180.26	270.48	0.33	90.67	180.27	270.48	Do.
1912										
Feb. 27	Antipolo.......	0.40	90.77	180.32	270.53	0.40	90.74	180.34	270.55	Do.
June 15	Suva Vou......	0.35	90.78	180.33	270.53	0.39	90.73	180.33	270.54	Do.
Sept. 26	Papeete........	0.38	90.74	180.33	270.55	0.39	90.73	180.33	270.54	Do.
1913										
Feb. 10	Port Stanley....	0.33	90.70	180.27	270.52	0.35	90.68	180.28	270.49	Do.
May 5	Jaburu, Bahia..	0.43	90.79	180.34	270.58	0.43	90.77	180.37	270.58	Do.
July 15	Longwood[2].....	0.41	90.73	180.27	270.79	0.37	90.71	180.31	......	Do.
Sept. 15	Falmouth......	0.33	90.70	180.29	270.55	0.35	90.69	180.29	270.50	Do.
1914										
Jan. 28	Washington.....	0.36	90.73	180.27	270.55	0.37	90.71	180.31	270.52	Do.
Means..........						0.37	90.71	180.31	270.52	

[1]Rejected in mean because of weak station-difference. [2]Observed value of E scale rejected.

v.—The value v of one scale division is obtained from the theodolite pointings on the various divisions. In a well-constructed instrument it should be so nearly 1 degreee that for a fraction of a degree it may be taken as unity. This offers the opportunity of saving one step in the sea calculations. It is, however, most important that v remain constant throughout any one scale.

m.—The inclination of each scale is determined independently, but for opposite scales the values are connected by the relations

$$(90^\circ - m_s) + (90^\circ - m_n) = R_s^I \qquad (90^\circ - m_w) + (90^\circ - m_e) = R_s^{II}$$

or

$$m_s + m_n = 180^\circ - R_s^I \qquad m_e + m_w = 180^\circ - R_s^{II}$$

where R_s^I and R_s^{II} are constant, so long as there are no structural changes in the optical systems. They also may be determined by simultaneous observations with two theodolites.

From simultaneous measurements made with two theodolites at Antipolo, March 1912, the following relations were established:

$$m_s + m_n = +\,0\overset{\circ}{.}18 \qquad m_e + m_w = +\,0\overset{\circ}{.}40$$

The values of m_e and m_w are constant. The values of m_s and m_n change with varying values of the vertical component Z of the Earth's magnetic field. The relation to Z is deduced from observations, and appears to be expressed by the linear equation

$$m = a + cZ$$

Then, for each station there is an observation equation of the form

$$a + cZ = m_s$$

and, on account of the relation

$$m_s + m_n = +0\overset{\circ}{.}18$$

another, thus:

$$a + cZ = +0\overset{\circ}{.}18 - m_n$$

Writing m_{sn} for $\frac{1}{2}(m_s + 0\overset{\circ}{.}18 - m_n)$, the above two observation equations may be written as a single equation as follows:

$$a + cZ = m_{sn}$$

The adjustment may then be made with a single equation for each station.

The adjustment for the first and second cruises of the *Carnegie* gives

$$m_{sn} = m_s = -\,0\overset{\circ}{.}75 + 1\overset{\circ}{.}27\ Z$$

and from the relation $m_s + m_n = +0\overset{\circ}{.}18$, there results

$$m_n = +\,0\overset{\circ}{.}93 - 1\overset{\circ}{.}27\ Z$$

The observed values of m_{sn}, and the values computed from the above are given, together with their differences, in Table 50. The values of m_e and m_w, after having been adjusted to the condition of $m_e + m_w = +0\overset{\circ}{.}40$, are likewise found in the table; their mean values are also given, since m_w and m_e do not vary with Z.

A *word of caution* may not be out of place regarding determinations of all constants of this compass, but particularly for R^I, R^{II}, R^{III}, R^{IV}, R_s^I, R_s^{II}. The instrument should be shielded from the direct rays of the Sun, which, by heating certain parts unequally, may cause small displacements that may be magnified many times through the optical system. The bowl should be drummed just before making each pointing on the scale, to overcome friction at the pivot.

TABLE 50.—*Values of the Scale Inclinations, m.*

Date	Station	m_{sn} Obs'd	m_{sn} Comp'd	m_{sn} $O-C$	m_w	m_e
1909		°	°	°	°	°
Jan. 27.....	Washington.....	−0.10	−0.03	−0.07	+0.40	0.00
July 26.....	New York, Bronx	−0.08	−0.02	−0.06	+0.37	+0.03
Oct. 25, 29..	Falmouth......	−0.19	−0.20	+0.01	+0.38	+0.02
1910						
Jan. 14, 18..	Bermuda.......	−0.08	−0.10	+0.02	+0.41	−0.01
Mar. 9, 10..	New York, Bronx	+0.01	−0.02	+0.03	+0.41	−0.01
June 13.....	Greenport......	−0.02	−0.03	+0.01	+0.48	−0.08
Aug. 2.....	Vieques........	−0.33	−0.31	−0.02	+0.44	−0.04
Oct. 4.....	Pinheiro........	−0.55	−0.59	+0.04	+0.48	−0.08
Dec. 12.....	Rio de Janeiro ..	−0.84	−0.83	−0.01	+0.47	−0.07
1911						
Jan. 24.....	Pilar...........	−0.92	−0.90	−0.02	+0.49	−0.09
Mar. 30.....	Cape Town.....	−1.14	−1.14	0.00	+0.51	−0.11
June 19.....	Colombo.......	−0.79	−0.78	−0.01	+0.53	−0.13
Nov. 10.....	Batavia........	−1.04	−1.03	−0.01	+0.56	−0.16
1912						
Feb. 27.....	Antipolo.......	−0.60	−0.61	+0.01	+0.61	−0.21
June 15.....	Suva Vou.......	−1.09	−1.10	+0.01	+0.60	−0.20
Sept. 26.....	Papeete........	−1.02	−0.99	−0.03	+0.55	−0.15
1913						
Feb. 10.....	Port Stanley....	−1.07	−1.09	+0.02	+0.54	−0.14
May 5.....	Jaburu, Bahia...	−0.72	−0.76	+0.04	+0.56	−0.16
July 15.....	Longwood......	−1.00	−0.97	−0.03	+0.57	−0.17
Sept. 15.....	Falmouth......	−0.14	−0.20	+0.06	+0.58	−0.18
1914						
Jan. 28.....	Washington.....	−0.02	−0.04	+0.02	+0.50	−0.10
Means........					+0.50	−0.10

METHOD OF SEA OBSERVATIONS.

If the instrument has just been mounted, or if the vessel has changed her course since the last observation, the cylinder is oriented some 5 minutes before observations, so as to avoid producing currents in the liquid by a sudden or large turn of the cylinder at the beginning of the observations. Determinations at sea may be made by one observer, assisted by one recorder (see Pl. 11, Fig. 3). But it is desirable to have another observer to measure the altitude of the object sighted in the middle of a set of 10 or 11 readings, and some one to keep the cylinder oriented when the vessel yaws more than 2°.

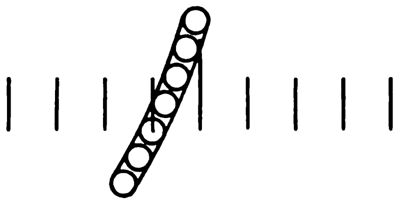


FIG. 12.

Figure 12 represents a projection of a scale upon a plane perpendicular to the collimator axis, so that, if held in a vertical position at arm's length in the direction of the selected cardinal point, it would give a fair perspective of the scale. As the sextant is rotated about its line of sight, the star's (Sun's) image is seen in successive positions indicated by the circles. A rapid swing to and fro through a small arc, by persistence of vision, produces a bright line or bar, so that the scale can be read at any instant, even when its motion is quite rapid, provided, of course, that it is not lost to view. Herein lies the difficulty for the novice, especially if there is much rolling or pitching. But, having once acquired the skill necessary to preserve a continuous view of the scale, he has no difficulty in projecting the image of the star upon it, by rotating the sextant as above described.

The star's (Sun's) image is observed for one or two oscillations to determine mentally the amplitude. It is then quickly moved by the index arm so that it oscillates to equal

distances on each side of the middle or long mark. The scale value is thus practically eliminated. Care is taken to read *along the upper portion* of the scale, since the inclination, m, is determined for an imaginary line just touching the upper ends of the small divisions. This becomes more important as the star's (Sun's) altitude increases. In Figure 12 the correct reading is 4.5, whereas the reading 4.0 at the bottom of the scale would be erroneous. The observer should shift his eye and the sextant so as to keep the middle division in the center of the mirror. The Sun's image is kept *close to the edge of the silvered portion* of the horizon glass of the sextant.

It may be noted that, since opposite scales are so nearly 180° apart in any plane common to both, the star's (Sun's) image for the second observation may readily be found by setting off the supplement of the sextant reading of the first observation, providing opposite scales are used. If opposite scales are employed symmetrically in a series of observations, constant errors of the sextant are eliminated, as may be seen from equation (6), since, by convention, Δ is positive for one scale and negative for the other.

A "set" consists of 10 or 11 readings of the scale, taken at extremes of the oscillations, or at precisely equal intervals of time. The observer calls out "mark" at each reading, and the time is noted. During a "set" the index arm or screw is not touched, so that the sextant reading corresponds to the mean of the set. The observer "standing by" to measure altitudes notes the altitude at the fifth or sixth reading, or between the fifth and sixth, according to the proposed number of readings. (See Pl. 15, Fig. 2.)

Specimens of observations and computations are given on pages 213-215.

SEA DEFLECTOR FOR MAGNETIC HORIZONTAL INTENSITY AND DECLINATION.

Early in 1905, in order to supplement the sea dip-circle for obtaining magnetic intensities at sea, a deflecting apparatus was devised by L. A. Bauer which could readily be attached to an ordinary liquid compass, and make possible the direct determination of the magnetic horizontal intensity, as well as of the magnetic declination.[1] The "sea deflector" has been used throughout the ocean work accomplished on board the *Galilee*, 1906-1908, and on the *Carnegie*, 1909-1916. The following paragraphs briefly describe the instrument in its later improved forms as used on the *Carnegie*, and as constructed in the Department's instrument shop, under the direct supervision of J. A. Fleming, who is responsible for many of the improvements. The special requirements of the instrument were simplicity of construction, of observation, and of computation, and availability both for observations of declination and horizontal intensity. The earlier forms of the instrument used in the *Galilee* work will be found described on pages 24-26.

DECLINATION OBSERVATIONS.

As a check upon the declination results with the standard compass, the sea deflector, while designed chiefly for horizontal-intensity observations, has been steadily improved, so that with it good declination values also may be obtained. This has been accomplished by constructing the compass part of the deflector practically ourselves and embodying the improvements described later. Three instruments of this type (D3, D4, and D5) have been successively constructed in the Department's instrument shop, and supplied to the *Carnegie*. The instrument in its final form is no longer a mere attachment to a compass supplied by mercantile makers, but is now entirely a distinctive product of the Department of Terrestrial Magnetism. Had the original name, "sea deflector," not already been used, it might now be more appropriately termed a "sea magnetometer," as with it both the magnetic declination and the horizontal intensity are determined at sea.

[1]For first descriptions of the instrument, see articles by L. A. Bauer and J. A. Fleming in *Terr. Mag.*, vol. 11, pp. 78-83, 1906; vol. 14, pp. 167-169, 1909; vol. 18, pp. 57-62, 1913. See also this volume, pp. 24-26 and 191.

the improvements introduced being based on the experience obtained with deflectors 1 and 2 on the *Galilee's* cruises. The first instruments had shown some inherent defects caused chiefly by the fact that navigation compasses already on hand had to be used. The improvements in No. 3 were along lines similar to those introduced in No. 4, differing in detail as indicated in the following description of the latter instrument.

Sea deflector 4.—Additional experience showed that it would be preferable to make the observations with deflecting magnet both above and below the card, that the graduation ordinarily found on even the best of compass cards was not as good as was desirable, and that a continuous graduation from 0° to 360° would prove advantageous. Furthermore, the varying conditions of temperature encountered in ocean work and the accompanying unequal expansion of the various instrumental parts caused at times a sticking or binding of the bearing surfaces, thus making it hard to secure accurate settings. To overcome these difficulties sea deflector 4 was designed and constructed by the Department; this instrument is shown in Plate 12, Figures 2–9. It will be described in detail, as it is the type used on board the *Carnegie* since 1911.

It differs from No. 3 in that there are now two standards or deflecting arms, so that the magnet may be mounted either above or below the compass card. Each standard has provision for 4 corresponding deflection distances. These deflection distances are approximately the same as were those in No. 3, viz, 172, 182, 192, and 201 mm. The upper standard, with the exception of the clamping device for holding the deflecting magnet in position, is made in one piece and so designed that it also serves in a general way to protect the sight vanes used in connection with the declination work. For avoiding parallax, two pieces are attached to the upper deflection standard, having "V" cuts placed centrally with the line of sight of the vanes. (See Pl. 12, Fig. 4.)

The card graduation for this instrument (see Pl. 12, Figs. 7 and 9) is made on German silver, and is continuous from zero at the magnetic north point in a clockwise direction, as seen from above, through 360 degrees, the least count being 1 degree. Every 10-degree graduation is numbered, thus, 1, 2, 3, 4, etc., to 35. The 5-degree graduations are distinguished by somewhat greater length than single-degree graduations. The diameter of the graduation of the card is 178 mm. The surface of the compass magnets and of the brass flange carrying the graduated circle, as well as the graduated surface, have all been silver-plated and made black, so that the graduations stand out as white lines against a black background. The bottom of the inside of the bowl has also been blackened, but the sides have been left with the bright silvered surface in order to provide, by reflection, suitable illumination for the graduation. The north point of the card has been marked by an arrow on the brass surface of the supporting flange and the other cardinal points have been marked by means of straight lines. As in the case of No. 3, the rim of the bowl is graduated into 1-degree intervals, every 10-degree graduation being numbered; two verniers are provided which permit reading to 0°.1 and estimation to 0°.05. The diameter of this graduation is 248 mm.

The bowl, as in the case of No. 3, has a cone bearing in its inner gimbal-ring. In order, however, to effect greater ease of motion and, secondly, accuracy of setting, a ball bearing is provided, the adjustment of which is such that the cone surfaces are used for centering purposes, while the balls carry the weight of the instrument. The detail of this bearing is shown in Plate 12, Figures 5 and 6. Directly over the knife-edge supports of the bearing ring are two pinions with milled heads, which may be used in finer setting of the bowl, the rack for this motion being fastened to the under side of the graduated rim. A single clamp is provided for clamping the bowl in its bearing; this clamp, however, is not for use in the sense of a slow motion in connection with the rack, but is merely provided to hold the bowl in position when necessary, and for use with the device for measuring angles between prominent objects when entering or leaving a harbor.

sighting vane L1 has been provided with arrangements for two slides, one for the plano-parallel glass with reference line, and the other for the color-glass shade; (*h*) the vertical ground-glass pieces with reference lines for the azimuth work are mounted by clamps instead of, as in No. 4, by screws, thus permitting a more permanent adjustment, and eliminating the danger of breakage occasioned by drilling of glass plates; (*i*) the line of reference on the cover plate is white instead of black, as for No. 4. (For views of No. 5, see Pl. 13.)

SCHEME OF HORIZONTAL-INTENSITY OBSERVATIONS.

In the following scheme of observations for horizontal intensity, the deflection distances, in the order of increasing magnitude, are designated for the upper standard as U1, U2, U3, and U4; for the lower standard they are similarly, L1, L2, L3, and L4. For distances 1 and 3, the sight line is L2 to 180° and L2 to 0°, and for distances 2 and 4, L2 to 270° and L2 to 90°. Observations for horizontal intensity are made in general by using two deflection distances, for example, U1 and L1 together with U3 and L3. The scheme for distances 1 and 3, comprising 16 positions, will illustrate the general method of observation. From the readings there results a value of the deflection angle, *u*, for each distance, outstanding defects of instrumental adjustments being eliminated, as well as possible, by the scheme of observation. For each position there are taken as many readings as circumstances require, for example, 5, in the sea work.

Position *a*.	Sight line L2 to	180°,	north end of deflecting magnet	east,	distance	U1	Reading vernier *A*
" *b*.	" " " "	180°,	" " " " "	east,	"	L1	
" *c*.	" " " "	0°,	" " " " "	west,	"	L1	
" *d*.	" " " "	0°,	" " " " "	west,	"	U1	
" *e*.	" " " "	0°,	" " " " "	west,	"	U3	Reading vernier *A*
" *f*.	" " " "	0°,	" " " " "	west,	"	L3	
" *g*.	" " " "	180°,	" " " " "	east,	"	L3	
" *h*.	" " " "	180°,	" " " " "	east,	"	U3	
Position *i*.	Sight line L2 to	0°,	north end of deflecting magnet	east,	distance	U3	Reading vernier *B*
" *j*.	" " " "	0°,	" " " " "	east,	"	L3	
" *k*.	" " " "	180°,	" " " " "	west,	"	L3	
" *l*.	" " " "	180°,	" " " " "	west,	"	U3	
" *m*.	" " " "	180°,	" " " " "	west,	"	U1	Reading vernier *B*
" *n*.	" " " "	180°,	" " " " "	west,	"	L1	
" *o*.	" " " "	0°,	" " " " "	east,	"	L1	
" *p*.	" " " "	0°,	" " " " "	east,	"	U1	

Readings of the ship's heading on a reference compass (see p. 203) are made by a second observer, simultaneously with each deflector reading. These compass readings are, of course, necessary only for observations at sea, not on land, their purpose being merely to determine the changes in ship's heading during deflector observations.

The scheme of observation is similar for distances 2 and 4, using the sights stated above. The times of beginning and ending for each distance, as well as the temperatures, are recorded. For low values of *H*, the longer deflection-distances are used.

In order to avoid any drag of the magnet card, 2 full minutes are allowed at the beginning of observation for each magnet (not distance) after the magnet is in position, as also between each reversal of sights and bowl; a full minute is allowed between all other positions.

The minimum time required for a half set, from the beginning of reading to the end, is about 8 minutes, but in general, making allowance for interruption and repetition, about 10 minutes are required. All possible precautions are taken against setting up motion of the liquid in the bowl by sharp reversals of sights and bowl, as well as to avoid lifting the card off the pivot by the action of the deflecting magnet during reversal of the bowl, the deflecting magnet being removed during such reversals and held sufficiently far away to have no effect. The complete set, using two distances, with repetitions of readings, as may

be required by the conditions of sea, is made to extend over nearly an hour's time, during which simultaneous dip and intensity observations are made in the forward observatory with the sea dip-circle. The sea deflector is mounted in the after observatory. Plate 12, Figure 2, shows observations being made with the instrument mounted aboard the *Carnegie*.

A specimen of sea observations and of computations will be found on page 217. For specimen illustrating the determination of instrumental constants at shore stations, see page 240.

SEA DIP-CIRCLE FOR INCLINATION AND TOTAL INTENSITY.

The modified form of sea dip-circle, described in connection with the *Galilee* work (pp. 21–23), was used throughout the cruises of the *Carnegie*, 1909–1916. A new, reversible gimbal-stand, however, on which the sea dip-circle is mounted, was designed and the new portions were constructed in the instrument shop of the Department (for description, see pp. 196–197, and Pl. 14, Fig. 5). The new stand was installed on the *Carnegie* during Cruise II, at Tahiti in 1912. With this stand, the effect of any lack of level of dip circle during observations may be more effectively eliminated or minimized than previously. Before the introduction of the new stand, as well as since, the same precautions were taken to control level of dip circle as were observed in the *Galilee* work (see p. 22). For views of the sea dip-circle used, see Plate 4, Figure 3, and Plate 14, Figure 1.

Both deflection distances, as provided in the modified sea dip-circle, have proved available for all the *Carnegie* cruises, with the exception of a small portion on Cruise II in 1913, when the vessel was off the Brazilian coast and near the magnetic equator; in this region the short deflection-distance could not be used, but no difficulty was experienced with the long distance. During the period November 18, 1910, to March 7, 1911, when deflections at short distance were not possible, double the usual number of intensity observations with the loaded needle were made.

Various investigations have been made with respect to the improvement of the loaded-dip observations. In quiet waters, intensity results of value may be obtained from these observations, if made with care. Whenever there is any considerable motion of ship, however, especially of rolling and pitching, then dynamic effects enter as the result of the comparatively large leverage of the eccentric load on the needle, the load or weight being inserted in the blade of the needle near one of its ends. At such times but little use, if any, can be made of the observations. Accordingly, throughout, chief dependence has been placed on the intensity results from the deflection observations, though the loaded-dip results have been used whenever observing conditions warranted doing so.

In the original design of the sea dip-circle it was intended that for the loaded-dip observations the load or weight inserted in the needle should be shifted from one end of needle to the other when passing from one magnetic hemisphere to the opposite one. In the northern magnetic hemisphere, for example, the suitably selected weight was to be inserted in the south-seeking end, or in the end of the needle which was above the horizon. In the southern magnetic hemisphere, on the other hand, the weight was to be inserted in the north-seeking end of needle. It was even intended that the weight should be varied from time to time according to the magnetic latitude of the region of work. For this purpose spare weights are provided, some of which, because of lack of marking, could readily be confused with one another. Accordingly, a simple brass case was designed to contain these weights, with such appropriate designations as to avoid possible confusion. Referring to Plate 14, Figure 2, 6 holes will be seen in which the various weights are inserted. A weight placed in the hole between the figures 1 and 1 is designated weight 11; weight 12 is the one in the hole between the figures 1 and 2. The lengths of the weights, which were made of German silver, were also measured in order to help to identify them.

We have not found it advantageous on a cruise to vary the weight or its position from one end of the needle to the other. According to test observations at Washington, or at some port, the most suitable weight, answering as well as possible the theoretical requirements for a cruise, is selected. Thereafter no change is made, except, of course, in case of accident. The intensity constant is, however, controlled by shore observations at every port of the cruise.

In general, if sufficient opportunities are presented to make control observations of the intensity constants at ports about once a month, and if adequate care is taken of the intensity needles, it is quite possible to eliminate the more or less troublesome loaded-dip observations and rely entirely on the deflection observations, if they are made with the precautions taken on the *Carnegie*.

MARINE EARTH-INDUCTOR FOR INCLINATION.

One of the problems[1] encountered in ocean magnetic work covering an extensive area has been the satisfactory determination of the variations, with change in magnetic latitude, of the inclination-corrections on standard for dip-circle needles. This problem has been the more difficult because of the mechanical impossibility (despite the most skillful and careful workmanship) of producing a perfect axle. Up to the present time the corrections on standard have been obtained with the aid of the observation at the ports visited, where intercomparisons were secured between a standardized earth-inductor and the sea dip-circles. A second problem, as yet unsolved, is the determination of possible dynamic effects[2] upon the direction taken by the needle during observations because of the ship's motion. Since the shore stations are often widely separated, and the conditions aboard ship, where the instruments and needles are in constant motion, are so very different from those on shore, it became desirable that some form of instrument should be devised for the purpose of securing standardizations and the required control on board ship, *i. e.*, in transit from port to port. The satisfactory performance of the earth inductors of various makes and designs, as evidenced by the extensive intercomparison work of the Department of Terrestrial Magnetism,[3] indicated that this type of instrument, if it could be made applicable for observation at sea, might be so utilized. After an extended theoretical study[4] of all the conditions involved, the design and construction of the desired apparatus in the Department's instrument shop were undertaken under J. A. Fleming's supervision.

DESCRIPTION.[5]

The elements of the marine earth-inductor are essentially: (*a*) an improved form of gimbal stand that will maintain an average mean position of equilibrium and will permit complete reversal of the gimbal rings and bearings in order to eliminate errors of level; (*b*) a portable form of earth inductor with such means for rotating the coil as will not in any way, when in use, disturb the gimbal rings, and (*c*) a galvanometer of sufficient sensibility suitable for use at sea.

Gimbal stand.—Heretofore the gimbal stand used has been of the type manufactured by Dover, of England. It consists of a suitable deck-support with a U-shaped arm at the top carrying a heavy supporting ring. Two brass knife-edges, mounted diametrically opposite in this ring, support a second ring, which in turn carries (at the ends of the diameter at right angles to and in the same horizontal plane as that used in the first ring) two brass

[1] *Cf.* Bauer, L. A. Some of the Problems of Ocean Magnetic Work. *Terr. Mag.*, vol. 14, pp. 164–166, 1909.

[2] Preparations are under way for an experimental investigation of this problem at Washington by means of observations on a platform which may be given various motions corresponding to those of a ship at sea.

[3] *Cf.* Fleming, J. A. Comparisons of Magnetic-Observatory Standards by the Carnegie Institution of Washington. *Terr. Mag.*, vol. 16, pp. 61–84 and 137–162, 1911.

[4] *Cf.* Dorsey, N. E. The Theory of the Earth Inductor as an Inclinometer. *Terr. Mag.*, vol. 18, pp. 1–38, 1913.

[5] *Cf.* J. A. Fleming's article in *Terr. Mag.*, vol. 18, pp. 39–45, 1913.

duced, this was not done. Care was used, however, to set the brushes very closely to eliminate the necessity, for practical purposes, of this adjustment. The vertical circle is 10.2 cm. in diameter, with a least graduation of 30 minutes of arc, and may be read directly, by two fixed verniers, to 1 minute and, by estimation, to one-quarter of a minute. Suitable means for clamping vertical circle and for slow motion are provided.

The bearings of the rotation axis of the coil are of brass, being V-shaped in longitudinal section and running in agate cups burnished in the brass centering supports in the supporting ring. The coil is held in place by two U-shaped pieces of brass which carry the bearing ends of the rotation axis. At one end of the rotation axis is mounted the commutator and at the other end is a miter gear for use in the rotation of the coil. The spool of the coil is made of hard rubber[1] of 24 mm. outside thickness and of 74 mm. outside diameter. The inside diameter of the winding of the coil is 26 mm., the outside diameter, 73 mm., and the width of winding, 17.5 mm. There are 65 layers (3,162 turns) of double-silk-wound magnet wire No. 30 B. & S. gage, with a double thickness of paper at every fifth layer. For protection against moisture conditions encountered on board ship and against possible abrasion and short-circuiting of the turns, the outer surface of the coil and its connections are heavily coated with paraffin. The resistance of the coil is about 175 ohms.

The instrument has been very carefully balanced by the use of counterweights attached (as has been found necessary) to the parts which may take up different positions at different times of observation; *e. g.*, the coil in its mounting has been carefully balanced around the axis supporting the bearing ring, and the whole has been balanced about the center line of the spindle bearing. Thus, when the instrument is mounted, the gimbal ring is supposed to remain level for any orientation or position of any part of the instrument.

For the purpose of determining the magnetic meridian, a sighting telescope and a compass are provided, suitable mounting wyes being placed so that the line of sight or the magnetic axis of the needle will be in the vertical plane through the rotation axis of the coil. The magnetic meridian may thus be determined by sighting upon marks of known magnetic bearing or by actual observation of the compass. Parallax in the compass readings is avoided with the aid of mirrors mounted immediately below the ends of the needle.

The gearing for rotating the coil of the earth inductor is self-contained, and is shown clearly in Plate 14, Figure 5. A hole has been drilled through the center of the spindle and a shaft mounted in it with a miter gear at the upper end in suitable bearing; this engages a second miter gear mounted on a shaft set at about 45° from the vertical in fixed bearings on the standard frame. A third gear at the upper end of the inclined shaft engages a similar miter gear attached to an axle rotating in the center of the horizontal bearing-end of the supporting ring. Inside of the supporting ring there is attached to this axle a gear of 102 teeth mounted in a hollow spherical frame which permits the coil to turn freely inside it, and which engages a gear of 25 teeth attached to the rotation axis of the coil.

The method of transmission of the rotary motion without disturbing the gimbal rings is as follows: At the point of intersection of the two diameters through the supporting knife-edges of the two gimbal rings a very small universal joint has been mounted; this is made so as to be adjustable vertically and has sufficient lost motion between its two parts to allow for the very slight play between the two rings in their bearings. The motion is transmitted to this universal joint by means of two gears, shafts, and a handle (see Plate 14, Fig. 5) carried in a frame attached rigidly in a diameter of the reversible bearing ring of the gimbal. By means of a slight inclination of the support carrying the transmitting shaft, it is possible to rotate the operating crank in any position of the ring without interference from the supporting frame. A cross-pin in the lower end of the rod through the spindle

[1]This material was used instead of brass because of the greater mechanical ease of maintaining insulation and eliminating induction effects.

therefore, necessary to observe deflections for particular settings of the rotation axis of the coil on either side of the line of magnetic inclination, taking care that a constant speed of rotation is maintained. With the aid of chronometer beats,[1] experiment has shown that there is comparatively little trouble in holding the speed sufficiently constant for practical purposes, account being taken of the desired accuracy of deflection determination for the comparatively small displacements from the line of actual magnetic inclination. By observing the mean deflections of the galvanometer for right-hand and left-hand rotation of the coil, respectively, when the rotation axis is in the magnetic meridian, it is possible to determine at once the position of balance, or the vertical-circle reading of the true line of inclination, by linear interpolation from the vertical-circle settings used. There being no means provided to determine directly the reading of the vertical circle when the rotation axis is vertical, corresponding observations and interpolations must be made with the vertical circle turned in azimuth 180° from its first position. The graduation is continuous through 360°, so that the difference between the two positions for balance so determined gives twice the complement of the angle of magnetic inclination, from which the value may be at once deduced.

Credit is due Mr. J. A. Widmer, chief instrument-maker of the Department, and his assistants, for the excellent execution of the mechanical detail.

INSTALLATION ON THE CARNEGIE.[2]

The apparatus was installed on board the *Carnegie* at Papeete, Tahiti, in October 1912. The inductor was mounted on the new gimbal-stand (Pl. 14, Fig. 5) in the forward observatory, *B* (see Pl. 9, Fig. 2). In order to eliminate any possible magnetic effect arising from the large field magnet of the galvanometer, it was necessary to place the galvanometer at a considerable distance from the mounts for the magnetic instruments. During October to November 1912 it was fastened by a bolt passing through its hard-rubber base to a substantial shelf against a wood wall about 30 feet aft of the deflector. In December 1912 a small structure to house the galvanometer was built on the quarter deck just aft of the engine-room skylight. The galvanometer was then mounted on a shelf, about 49 feet distant from the deflector. Communication between the observers at the earth inductor and the galvanometer is established by means of a simple signaling device.

The chief difficulty at sea has been the maintenance of the adjustment of the galvanometer (see p. 201). It is feasible to adjust the system readily at shore stations so that a tip of 20° in any direction, with a scale distance of 58 cm., causes a change of not more than 1 mm. in the galvanometer zero. Fortunately, after some practice, it has been found possible to make the adjustment for balance on board, even when the sea is moderately rough, within 3 to 15 minutes, depending upon how badly the coil is out of balance and upon the character of the ship's motion. In moderately rough seas, the wandering of the zero is reduced to a range of 5 to 10 mm. when the galvanometer is used with a 100-ohm shunt. The failure to maintain balance at sea is also partly due to the temperature and humidity changes. Owing to the lack of symmetry in the balancing arrangements, it is difficult to throw the center of gravity of the coil into the line of suspension. By manipulation it has been found easier to place the center of gravity in a plane at right angles to the coil than in the plane of the coil; for this reason the galvanometer has been mounted with the plane of its coil fore and aft, since the roll of the ship is more effective than the pitch.

---

[1] Experiments were also made with a metronome, but that instrument was unsuited for timing purposes on board ship.
[2] From a report by C. W. Hewlett, *Terr. Mag.*, vol. 18, pp. 46–48, 1913, with modifications.

At times the successive determinations agree exactly; more frequently they differ by a few hundredths of a degree, and occasionally by three or four tenths of a degree. The causes of the occasional large variations have not been wholly determined. The earth-inductor observations are made on nearly every day the dip circle is used, sometimes before and after, and sometimes in the middle of the dip-circle work, so that the earth-inductor values and those of the dip circle apply to the same times and positions. Experiments have been made on board the *Carnegie* to determine the relative accuracy of successive determinations for inclination with the earth inductor, by continuing observations throughout a long period of time; in general the indications from such observations have been satisfactory. Thus of six determinations, all applying to the same position and time on one day, the extreme difference from the mean in the case of one value was 0°.25; of a second value it was 0°.18, while the other values differed by less than 0°.1 from the mean. Another day's work gave eight determinations, none of which differed from the mean by as much as 0°.1. On both days the ship was becalmed, so that the only motion was rolling and the change in heading with the drift was slow. The conditions, therefore, were rather favorable for earth-inductor observations, since it is possible to maintain the orientation of the inductor in the magnetic meridian by shifting, simultaneously with the change in the ship's heading, the rotating ring of the gimbal stand without interrupting or affecting the observations.[1] It is hoped that the mean values of the magnetic inclination determined at sea with the inductor may be depended upon finally to within an absolute accuracy of 3 minutes of arc.

MOUNTING OF MAGNETIC INSTRUMENTS ON THE CARNEGIE.

At *A*, the middle point of the bridge (see Fig. 13 and Pl. 9, Fig. 2), is mounted in its binnacle the marine collimating-compass, the chief instrument for determining the magnetic declination.

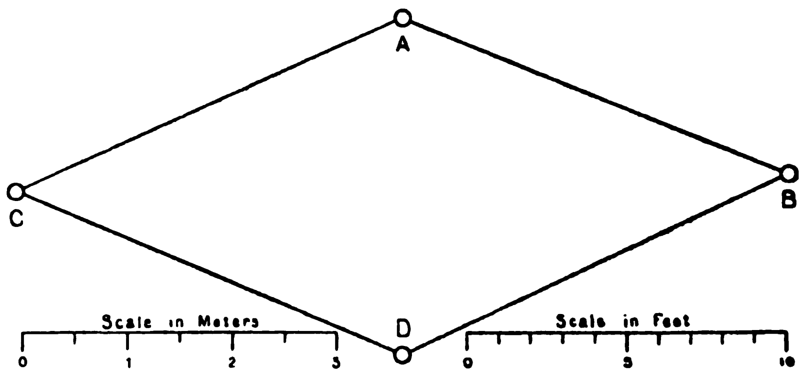


FIG. 13.—Showing Relative Positions of Magnetic Instruments on the Carnegie.

In the forward observatory, at *B*, the sea dip-circle was mounted until September 1912 on a Dover gimbal-stand, similar to the one at *E*, which was used for the atmospheric-electric observations from 1909–1914; since September 1912 the sea dip-circle (or the marine earth-inductor) is mounted on the special reversible gimbal-stand (see pp. 196–197). At *B* are made, accordingly, the observations for determining the magnetic inclination, I, and the total intensity, F, of the Earth's magnetic field. The horizontal intensity, H, is computed by means of the formula $H = F \cos I$.

The sea deflector is mounted in its binnacle in the after observatory, at *C*. With it are determined the horizontal intensity and the magnetic declination. The readings of ship's heading, which are made simultaneously with the H-observations at *C*, were taken

[1]The same conditions would be unfavorable for use of the sea dip-circle, since for that instrument it is not practical to shift the rotating ring of the gimbal stand during the observations.

and K; (4) Ritchie liquid compass 29971, provided with a brass binnacle-stand, by E. S. Ritchie and Sons, was used as a steering compass for the vessel; (5) Ritchie liquid compass 29499, and (6) Ritchie liquid compass 29497, the latter with its card ungraduated except for the 4 cardinal points, with azimuth circles 418–III and 481–III, all by E. S. Ritchie and Sons, were carried for reserve and experimental use.

II. *For magnetic inclination and total intensity at sea.* (1) Sea dip-circle 189,[1] provided with dip needles 5, 6, 9, and 10, intensity-needle pairs 3 and 4, and 7 and 8, brass gimbal-stand 2 (maker's number 189) for use on board ship, and tripod for use on shore, all by A. W. Dover, with improvements in design and construction specified by the Department of Terrestrial Magnetism; (2) sea dip-circle 203, a reserve instrument, provided with dip needles 1, 2, 5, 6, 9, and 10, and intensity-needle pairs 3 and 4, 7 and 8, and 11 and 12, brass gimbal-stand 3 (maker's number 208) for use on board ship, and tripod 203 for use on land, all by A. W. Dover, with improvements in design and construction as specified by the Department of Terrestrial Magnetism. The designations adopted, respectively, for the two dip circles are the numbers of the dip circles followed by numbers of needles used, intensity-needle numbers being italicized, thus: 189.9,10,*78*. When both deflection and loaded-dip observations were made the designation for the intensity needles is followed by a dagger (†), thus, 189.9,10,*78*†.

III. *For horizontal intensity at sea.* (1) Sea deflector 3, designed and constructed by the Department of Terrestrial Magnetism, provided with deflecting magnets 45 and 2L, brass binnacle-stand by E. S. Ritchie and Sons for use on board ship, and tripod 1 for use on shore. The designation adopted for the deflector and compass is D3.

IV. *For magnetic declination and horizontal intensity on land.* (1) Theodolite magnetometer 2, provided with tripod 2, by the Bausch and Lomb Optical Company according to specifications of the Department of Terrestrial Magnetism; (2) theodolite magnetometer 4,[2] provided with tripod 4, by the Bausch and Lomb Optical Company, and similar to magnetometer 2. The designations adopted, respectively, for the two magnetometers are 2 and 4.

V. *For magnetic inclination on land.* (1) Land dip-circle 178, provided with dip needles 1, 2, 5, and 6, intensity-needle pair 3 and 4, compass attachment, and tripod, all by A. W. Dover; (2) land dip-circle 201, provided with dip needles 1 and 2, intensity-needle pair 3 and 4, compass attachment, and tripod 201, all by A. W. Dover. The designations adopted, respectively, for the two dip circles are 178.25 and 201.12 (the intensity needles and the extra dip needles were not used). (3) Sea dip-circles 189 and 203 with their needles and compass attachments were also used for shore observations.

ATMOSPHERIC-ELECTRIC INSTRUMENTS.

VI. *Instruments for observations in atmospheric electricity.* (1) Conductivity apparatus 2, complete with accessories, Gerdien's design, by Spindler and Hoyer; (2) Harm's standard condenser 1693, by Günther and Tegetmeyer; (3) dispersion apparatus 1416, Elster and Geitel's design, by Günther and Tegetmeyer, provided with electroscope 1416, dry-pile 1408, tripod 1309, and accessories; (4) electroscope 1437 by Günther and Tegetmeyer; (5) miscellaneous equipment, including dry-pile 1449, special insulators, ionization chamber 1, aluminum foil, etc.

SEXTANTS, CHRONOMETERS, WATCHES, AND DIP-OF-HORIZON MEASURER.

VII. *Sextants.* (1) Nos. 2575, 2611, 2943, and 2944, by Ponthus and Therrode (the last two instruments are specially designed for use at night); (2) No. 3265 by C. Plath; (3) Nos. 10756 and 10759 by the Keuffel and Esser Company; (4) unnumbered sextant by

[1]Dip circle 189 was thoroughly overhauled and repaired during June to July, 1909, in the shop of the Department of Terrestrial Magnetism.

[2]Magnetometer 4 was supplied with a new long deflection-bar prior to its assignment for Cruise I of the *Carnegie*.

L. Weule; (5) gyroscopic collimator and octant 2679 by Ponthus and Therrode; (6) pocket sextant 301, from October 28, 1909, by James J. Hicks; (7) unnumbered pocket-sextant by Troughton and Simms, loaned by W. J. Peters; (8) prismatic circle 11717 by Carl Bamberg.

VIII. *Chronometers and watches.* (1) Marine chronometers 1809 by T. S. and J. D. Negus, loaned by W. J. Peters, 2761 by G. E. Wilkins, 52917 by E. Dent and Company, 52918 by E. Dent and Company, 53151 by E. Dent and Company, 53157 by E. Dent and Company, 53862 by E. Dent and Company, with ship and gimbal cases; (2) pocket chronometers 253 by A. Kittel and 256 by A. Kittel, for shore work; (3) watches 2 by the Hamilton Watch Company, 90 by the Waltham Watch Company, and 91 (sidereal) by the Waltham Watch Company; unnumbered stop-watch.

IX. *Dip-of-horizon measurer.* Dip-of-horizon measurer 4048, model A, by Carl Zeiss.

METEOROLOGICAL INSTRUMENTS AND MISCELLANEOUS EQUIPMENT.

X. *Meteorological instruments.* (1) Aneroid barometers 4 and 7 by Ponthus and Therrode; (2) unnumbered aneroid barometer by L. Weule; (3) barograph 5142 by Richard Frères; (4) marine mercury-barometer 3948, English scale, provided with attached thermometer 3017, by H. J. Green; (5) boiling-point apparatuses 3 and 4 by the Department of Terrestrial Magnetism; (6) Marvin sling psychrometers 202, 204, and 205, by Schneider Brothers; (7) thermographs 40418 and 46032, by Richard Frères; (8) six-inch thermometers Bureau of Standards numbers 4140, 4146, 4149, 4150, 4151, 4154, 4157, 4159, 4160, 4161, centigrade scale, all by H. J. Green; (9) thermometers for hypsometric work at sea, Bureau of Standards numbers 3549 and 3551, by H. J. Green; (10) thermometers for hypsometric work on land, Bureau of Standards numbers 3553 and 3554, by H. J. Green; (11) maximum thermometer, Bureau of Standards number 1252, and minimum thermometer, Bureau of Standards number 1253, by H. J. Green; (12) exposed thermometer, Bureau of Standards number 1251, Fahrenheit scale, by H. J. Green; (13) reserve maximum thermometer 8094 and minimum thermometer 8070, both Fahrenheit scale, by H. J. Green; (14) reserve thermometer 4903, Fahrenheit scale, by H. J. Green.

XI. *Miscellaneous equipment.* (1) Artificial horizon 2, designed and constructed by the Department of Terrestrial Magnetism; (2) leather chronometer carrying-cases; (3) balances; (4) six Edison primary batteries with coil for reversing magnetization of sea dip-circle needles; (5) marine clocks; (6) two 3-inch liquid boat-compasses and brass binnacles; (7) dating and numbering machines; (8) drawing tools; (9) plate and film cameras; (10) leads for sounding; (11) marine glasses; (12) taffrail logs; (13) universal levels; (14) inclinometers; (15) instrument trunk-cases; (16) miscellaneous office equipment; (17) microscope 2 and accessories, by the Spencer Lens Company (maker's number 10477); (18) medical and surgical supplies and instruments; (19) developing tank for photographic work; (20) three-arm protractor 10031, by the Keuffel and Esser Company; (21) reading glasses; (22) Tanner non-magnetic 100-fathom sounding machine 1, by D. Ballauf (maker's number 245); (23) tapes; (24) non-magnetic observing pyramid tents, regulation land type, for shore work; (25) special non-magnetic wall tents 9 feet by 9 feet, for shore work; (26) tools; (27) typewriter; (28) small instrumental accessories; (29) water filter.

CRUISE II, JUNE 1910 TO DECEMBER 1913.

MAGNETIC INSTRUMENTS.

XII. *For magnetic declination at sea.* (1) Marine collimating-compass 1, same as for Cruise I, supplemented by theodolite 5 from March 1911, for determination of constants on shore;[1] (2) deflector 3, same as for Cruise I, supplemented by a special sighting device, in use through March 1911, when it was replaced by deflector 4, but was kept on board subsequently for reserve and experimental use; (3) deflector 4, designed and constructed by the Department of Terrestrial Magnetism, from April 1911, the same binnacle and tripod being used as for deflector 3; (4) Kelvin dry compass-bowl, same as for Cruise I. The designations adopted, respectively, for the 4 compasses with appurtenances are C1, D3, D4, and K. (5) Ritchie liquid compass 29971, provided with a brass binnacle-stand, by E. S. Ritchie and Sons, was used as a steering compass for the vessel; (6) Ritchie liquid compass 29499, and (7) Ritchie liquid compass 29497, with azimuth circles same as for Cruise I, were carried for reserve and experimental use; (8) Ritchie liquid compass 39670, provided with brass binnacle-stand, by E. S. Ritchie and Sons, mounted in the chart-house from September 1912.

XIII. *For magnetic inclination and total intensity at sea.* (1) Sea dip-circle 189, same as for Cruise I;[2] (2) sea dip-circle 203, same as for Cruise I,[3] until November 15, 1911, when the dip circle with its needles was returned to Dover for overhauling; (3) sea dip-circle 204, provided with dip needles 1, 2, 9, and 10, and intensity-needle pairs 7 and 8, and 11 and 12, all by A. W. Dover, with improvements in design and construction specified by the Department of Terrestrial Magnetism, was carried as a reserve instrument from October 1911; (4) marine earth-inductor 3, provided with reversible gimbal-stand, all designed and constructed by the Department of Terrestrial Magnetism, from September 1912, supplemented by moving-coil marine galvanometer 19498 (tube 19499), by the Leeds and Northrup Company, which was replaced in February 1913 by moving-coil marine galvanometer 20696 (tube 20697), by the Leeds and Northrup Company, metronome 309,[4] telescope and scale, and accessories. The designations adopted, respectively, for the four instruments with their appurtenances are 189.9,10,*78*, 203.12*34*, 204.12*78*, and EI3. For the dip circles the intensity-needle numbers are italicized; for cases where both deflection and loaded-dip observations were made the designation for the intensity needles is followed by a dagger (†), thus, 189.9,10,*78*†.

XIV. *For horizontal intensity at sea.* (1) Sea deflector 3, same as for Cruise I; (2) sea deflector 4, provided with special brass binnacle-stand for use on board ship and tripod for use on shore, all designed and constructed by the Department of Terrestrial Magnetism, from April 1911, with deflecting magnets 45 and 2L of deflector 3, and new magnet 3 from December 1912, and supplemented from September 1912 by Ritchie liquid compass 39670. The designations adopted, respectively, for the deflectors are D3 and D4.

XV. *For magnetic declination and horizontal intensity on land.* (1) Theodolite magnetometer 2, same as for Cruise I; (2) theodolite magnetometer 4, same as for Cruise I; (3) universal magnetometer 14, provided with all appurtenances and tripod 14, designed and constructed by the Department of Terrestrial Magnetism, from April to September 1913; (4) universal magnetometer 19, provided with tripod 19, designed and constructed by the Department of Terrestrial Magnetism, from September 1912 to May 1913; (5) theodolite magnetometer 8, provided with tripod 8, by the Bausch and Lomb Optical

[1]Between Cruises I and II tripod 2 was modified by the addition of an arm rotating about the center spindle, on which to mount the theodolite for the determination of constants on shore.

[2]The brass gimbal-stand 2 was replaced in September 1912 by the special reversible gimbal-stand provided for marine earth-inductor 3.

[3]The axle of needle 7 was broken on May 14, 1911; needle 1 was returned to the Office in January 1911.

[4]The metronome, originally intended as a timing device for maintaining constant speed of the rotation apparatus, was found unsuitable for use on board ship, and was replaced by a half-second chronometer.

Company according to specifications of the Department of Terrestrial Magnetism, was used at Cape Town during March 1911. The designations adopted, respectively, for the five magnetometers are 2, 4, 14, 19, and 8.

XVI. *For magnetic inclination on land.* (1) Land dip-circle 201, provided with dip needles 1, 2, 5, and 6, intensity-needle pairs 3 and 4, and 7 and 8, compass attachment, and tripod 201, all by A. W. Dover; (2) earth inductor 2, provided with tripod 2, galvanometer 206, tripod 206, and appurtenances, all by Otto Toepfer and Son, from September 1910; (3) universal magnetometer 14, provided with tripod 14, Dover dip needles 1, 2, 5, and 6, and intensity-needle pairs 3 and 4, and 7 and 8, designed and constructed by the Department of Terrestrial Magnetism, from April to September 1913; (4) universal magnetometer 19, provided with tripod 19 and Dover dip needles 1, 2, 5, and 6, designed and constructed by the Department of Terrestrial Magnetism, from September 1912 to May 1913; (5) marine earth-inductor 3 was also used for shore observations; (6) land dip-circle 172, provided with dip needles 1, 2, 5, and 6, intensity-needle pair 3 and 4, and tripod 172, all by A. W. Dover, was used at Cape Town during April 1911. The designations adopted, respectively, for the six instruments are 201.125, EI2, 14.1256, 19.1256, EI3, and 172.1256 (the intensity needles and the extra dip needles were not used).

ATMOSPHERIC-ELECTRIC INSTRUMENTS.

XVII. *Instruments for observations in atmospheric electricity.* (1) Batteries of cadmium cells, Krüger's design, by Spindler and Hoyer, as follows: 2 throughout cruise, 2 from July 1910, and 2 from February 1912; (2) Harm's standard condenser 1693, by Günther and Tegetmeyer; (3) conductivity apparatus 2, complete with accessories, Gerdien's design, by Spindler and Hoyer; (4) dispersion apparatus, Elster and Geitel's design, by Günther and Tegetmeyer; (5) Zamboni dry-piles 1449 throughout cruise, 3206 and 3230 from February 1912, and 3376 from September 1912; (6) aluminum-leaf electroscope, by Spindler and Hoyer; (7) electroscope 2, provided with appurtenances, Wiechert's design, by Spindler and Hoyer, from February 1912; (8) bifilar electroscope 3537, provided with appurtenances, Wulf's design, by Günther and Tegetmeyer, from December 1912; (9) 2 ionium collectors by Günther and Tegetmeyer, from February 1912; (10) 4 radium collectors, by F. H. Glew, 2 throughout the cruise, and 2 from June 1911; (11) sea-and-rain-water radioactivity-apparatus, by the Department of Terrestrial Magnetism, provided with lamp, electroscope 1437, and appurtenances; (12) voltmeter, from October 1913; (13) ammeter, from October 1913; (14) non-magnetic brass Gauss stand, constructed by the Department of Terrestrial Magnetism; (15) small non-magnetic gimbal-stand, from September 1912; (16) miscellaneous equipment, including non-magnetic brass-clamps, special insulators, flame collectors and supports, non-magnetic brass laboratory-supports and stands, ionization chamber 1, aluminum foil, small tools, Dewar flask, etc.

SEXTANTS, CHRONOMETERS, WATCHES, AND DIP-OF-HORIZON MEASURER.

XVIII. *Sextants.* (1) Nos. 2575, 2611, 2617 (from September 1912), 2943, 2944, by Ponthus and Therrode (the last two instruments are specially designed for use at night); (2) No. 3265 by C. Plath; (3) Nos. 10756, 10759, and 22876 (from September 1912), all by Keuffel and Esser Company; (4) unnumbered sextant by L. Weule; (5) gyroscopic collimator and octant 2679 by Ponthus and Therrode; (6) pocket sextant 301[1] by James J. Hicks; (7) extra small sextants 3380 and 3393 by Carey, Porter Ltd., from September 30, 1913; (8) unnumbered pocket-sextant by Troughton and Simms, loaned by W. J. Peters; (9) prismatic circle 11717 by Carl Bamberg.

[1]Sextant 301 was overhauled and repaired in the instrument shop of the Department of Terrestrial Magnetism in April 1910; at that time several small parts found to be slightly magnetic were replaced by non-magnetic parts.

XIX. *Chronometers and watches.* (1) Marine chronometers 254 by A. Kittel (from September 1912), 268 by A. Kittel (from September 1912), 1809 by T. S. and J. D. Negus, loaned by W. J. Peters, 2761 by G. E. Wilkins, 52917 by E. Dent and Company, 53151 by E. Dent and Company, 53157 by E. Dent and Company, 53862 by E. Dent and Company, with ship and gimbal cases; (2) pocket chronometers 256 by A. Kittel from March 1911, 258 by A. Kittel until December 1910, 260 by A. Kittel until September 11, 1911, 13733 by Paul D. Nardin, for shore work; (3) watches 51 by the Hamilton Watch Company, 90 by the Waltham Watch Company until October 1912, 91 (sidereal) by the Waltham Watch Company, 92 (sidereal) by the Waltham Watch Company from February 1913, 101 by the Elgin National Watch Company from September 1912, 813 by the Howard Watch Works from September 1912; unnumbered stop-watch.

XX. *Dip-of-horizon measurer.* Dip-of-horizon measurer 4048, model A, by Carl Zeiss.

METEOROLOGICAL INSTRUMENTS AND MISCELLANEOUS EQUIPMENT.

XXI. *Meteorological instruments.* Same as for Cruise I with the addition of the following: (1) Marine mercury-barometer 4177, English scale, provided with attached thermometer 11441, and gimbal attachment, by H. J. Green, from March 1911; (2) boiling-point apparatuses, 6 from October 1911, and 8 and 9 from February 1912, all by the Department of Terrestrial Magnetism; (3) Marvin sling psychrometers[1] 534, 537 (broken September 1910), 550 from October 1911, 556 from October 1911, 560 from October 1911, and 4 thermometers, centigrade scale, 1, 2, 9, and 15, all by Schneider Brothers, to replace broken psychrometer-thermometers, from June 1912; (4) thermograph 46034, by Richard Frères, to June 1912, and after repairs from September 1912; (5) six-inch thermometer,[2] Bureau of Standards number 6722, by H. J. Green, from May 1913; (6) boiling-point thermometers for work at sea,[3] Bureau of Standards numbers 6192 from February 1911, 6329 from February 1912, 6330 from June 1912, 6331 from March 1911, 6332 from March 1911, 7827 from June 1912, 7828 from June 1912, 8116 from September 1912, 8117 from September 1912, 8118 from September 1912, 8119 from September 1912, 8728 from September 1913, and 8729 from September 1913.

XXII. *Miscellaneous equipment.* Same as for Cruise I, with the addition of the following: (1) Electric flashlights; (2) experimental prism-holders 1 and 2 and prisms, by the Department of Terrestrial Magnetism.

CRUISE III, JUNE TO OCTOBER 1914.

MAGNETIC INSTRUMENTS.

XXIII. *For magnetic declination at sea.* (1) Marine collimating-compass 1,[4] same as for Cruise II; (2) deflector 4,[5] same as for Cruise II. The designations adopted, respectively, for the 2 compasses with appurtenances are C1 and D4. (3) Ritchie liquid compass 29971, same as for Cruise II; (4) Ritchie liquid compass 29499, and (5) Ritchie liquid compass 29497, same as for Cruise II; (6) Ritchie liquid compass 39670, same as for Cruise II; (7) Kelvin azimuth instrument 3619 for experimental use.

XXIV. *For magnetic inclination and total intensity at sea.* (1) Sea dip-circle 189,[6] same as for Cruise II, with dip needles 5, 6, and 9, and intensity-needle pairs 3 and 4, and

[1]Psychrometer 205 was broken in December 1910.

[2]Thermometer 4157 was on board until May 1913 only.

[3]The following thermometers were broken during the cruise: 3549, 3551, 6192, 6329, 6331, 7827, 8116, 8117, and 8118.

[4]Collimating compass 1 was overhauled and repaired, and improvements were made to the compass housing and binnacle stand during April to May, 1914, in the instrument shop of the Department of Terrestrial Magnetism.

[5]Deflector 4 was overhauled and repaired, and minor improvements were made during April to May 1914, in the instrument shop of the Department of Terrestrial Magnetism.

[6]Sea dip-circle 189 was overhauled and repaired and reading microscopes with larger fields were added during April to May 1914, in the instrument shop of the Department of Terrestrial Magnetism.

7 and 8; (2) sea dip-circle 204, same as for Cruise II; (3) marine earth-inductor 3,[1] same as for Cruise II, with the addition of moving-coil marine galvanometer 20698. The designations adopted, respectively, for the 3 instruments with their appurtenances are 189.56*978* 204.12*78*, and EI3. For the dip circles the intensity-needle numbers are italicized; for cases when both deflection and loaded-dip observations were made the designation for the intensity needles is followed by a dagger (†), thus, 189.56*78*†.

XXV. *For horizontal intensity at sea.* (1) Sea deflector 4, same as for Cruise II. The designation adopted for the deflector and compass is D4.

XXVI. *For magnetic declination and horizontal intensity on land.* (1) Theodolite magnetometer 5, provided with tripod 5, by the Bausch and Lomb Optical Company according to specifications of the Department of Terrestrial Magnetism; (2) magnetometer-inductor 25, provided with galvanometer and tripods, designed and constructed by the Department of Terrestrial Magnetism. The designations adopted, respectively, for the two magnetometers are 5 and 25.

XXVII. *For magnetic inclination on land.* (1) Magnetometer-inductor 25, provided with galvanometer, and tripod 25, designed and constructed by the Department of Terrestrial Magnetism. The designation adopted for the instrument is 25. (2) Marine earth-inductor 3 was also used for shore observations.

ATMOSPHERIC-ELECTRIC INSTRUMENTS.

XXVIII. *Instruments for observations in atmospheric electricity.* (1) Conductivity apparatus 2, same as for Cruise II; (2) Gerdien condenser by Spindler and Hoyer; (3) electroscope 2, same as for Cruise II; (4) electroscope 3995, provided with appurtenances, Wulf's design, by Günther and Tegetmeyer; (5) ion counter, provided with Zamboni dry-pile and accessories, after Ebert's design; (6) potential-gradient apparatus; (7) Braun electroscope 1437, same as for Cruise II; (8) three radium collectors and two ionium collectors, same as for Cruise II; (9) Zamboni dry-piles 1449, 3206, 3230, and 3376; (10) volt-ammeter; (11) potentiometer; (12) non-magnetic brass Gauss stand, same as for Cruise II; (13) small non-magnetic gimbal-stand, same as for Cruise II; (14) Weston voltmeter 11763; (15) two batteries of cadmium cells, Krüger's design, by Spindler and Hoyer; (16) miscellaneous equipment same as for Cruise II, with small additions, including a Simpson charging rod.

SEXTANTS, CHRONOMETERS, WATCHES, AND DIP-OF-HORIZON MEASURER.

XXIX. *Sextants.* Same as for Cruise II.

XXX. *Chronometers and watches.* (1) Marine chronometers 254 by A. Kittel, 264 by A. Kittel, 360 by Finer, 1044 by Roskell, 2761 by G. E. Wilkins, 52917 by E. Dent and Company, 53151 by E. Dent and Company, 53157 by E. Dent and Company, 53862 by E. Dent and Company, with ship and gimbal cases; (2) watches 51 by the Hamilton Watch Company, 101, 114, 115, and 117 by the Elgin National Watch Company, 813 by the Howard Watch Works; unnumbered stop-watch.

XXXI. *Dip-of-horizon measurer.* Dip-of-horizon measurer 4048, same as for Cruise II.

METEOROLOGICAL INSTRUMENTS AND MISCELLANEOUS EQUIPMENT.

XXXII. *Meteorological instruments.* Same as for Cruise II, except thermometers 1252 and 1253, with the addition of the following: (1) six-inch thermometers, Bureau of Standards numbers 9517, 9520, 9521, 9530, 9531, and 9532, by H. J. Green.

XXXIII. *Miscellaneous equipment.* Same as for Cruise II.

[1]Marine earth-inductor 3 was thoroughly overhauled and repaired during April 1914 in the instrument shop of the Department of Terrestrial Magnetism.

CRUISE IV, MARCH 1915 TO SEPTEMBER 1916.

MAGNETIC INSTRUMENTS.

XXXIV. *For magnetic declination at sea.* (1) Marine collimating-compass 1, same as for Cruise III; (2) sea deflector 4,[1] same as for Cruise III. The designations adopted, respectively, for the two compasses with appurtenances are C1 and D4. (3) Sea deflector 5, provided with deflecting magnet 5, designed and constructed by the Department of Terrestrial Magnetism, from April 1916, for reserve and experimental use; (4) Ritchie liquid compass 29971, same as for Cruise III; (5) Ritchie liquid compass 29499, and (6) Ritchie liquid compass 29497, same as for Cruise III; (7) Ritchie liquid compass 39670, same as for Cruise III; (8) sea deflector 3 was on board from June 1915 for possible emergency use.

XXXV. *For magnetic inclination and total intensity at sea.* (1) Sea dip-circle 189, same as for Cruise III, with dip needles 1, 2, 5, and 6, and intensity-needle pairs 3 and 4, and 11 and 12; (2) sea dip-circle 204, provided with dip needles 2, 9, 10, and 11, and intensity-needle pairs 3 and 4, and 7 and 8;[2] (3) marine earth-inductor 3, same as for Cruise III with the addition, for use at shore stations, of galvanometer 28A and tripod, designed and constructed by the Department of Terrestrial Magnetism. The designations adopted, respectively, for the three instruments and their appurtenances are 189.1256*34*, 204.29*34*, and EI3. For the dip circles the intensity-needle numbers are italicized; for cases where both deflection and loaded-dip observations were made, the designation for the intensity needles is followed by a dagger (†), thus, 189.12,*11*,*12*†.

XXXVI. *For horizontal intensity at sea.* (1) Sea deflector 4, same as for Cruise III. The designation adopted for the deflector is D4. (2) Sea deflector 5 with deflecting magnet 5 was on board from April 1916, as a reserve instrument; (3) sea deflector 3 was on board from June 1915 for possible emergency use.

XXXVII. *For magnetic declination and horizontal intensity on land.* (1) Theodolite magnetometer 5, same as for Cruise III; (2) magnetometer-inductor 25,[3] same as for Cruise III. The designations adopted, respectively, for the 2 magnetometers are 5 and 25. (3) Universal magnetometer 21, designed and constructed by the Department of Terrestrial Magnetism, was used at one shore station in March 1915.

XXXVIII. *For magnetic inclination on land.* (1) Magnetometer-inductor 25, same as for Cruise III; (2) land dip-circle 201, provided with dip needles 5 and 6 of 201, 5X, and 6X, and intensity-needle pair 3 and 4, with tripod 201, all by A. W. Dover, until May 9, 1916. The designations adopted, respectively, for the two instruments are EI25 and 201.56, 5X, 6X. (3) Marine earth-inductor 3 was also used for shore observations; (4) universal magnetometer 21, provided with needles 1 and 3 of 19, and 3 and 4 of 20, was used at one shore station in March 1915.

ATMOSPHERIC-ELECTRIC INSTRUMENTS.

XXXIX. *Instruments for observations in atmospheric electricity.* (1) Conductivity apparatus 3, designed and constructed by the Department of Terrestrial Magnetism, provided with gimbal rings and mounting, and direct-current motor; (2) ion counter 1, provided with gimbal rings and mounting, and appurtenances, all designed and constructed by the Department of Terrestrial Magnetism; (3) penetrating-radiation apparatus 1, provided with gimbal rings and mounting, and appurtenances, all designed and constructed by the Department of Terrestrial Magnetism; (4) potential-gradient apparatus 2, complete with appurtenances and mounting, all designed and constructed by the Department of

[1] Minor repairs were made during January 1915 on deflector 4 in the instrument shop of the Department of Terrestrial Magnetism.

[2] Intensity needles 7 and 8 and dip needle 9 were returned in April 1915, the pivots of 8 and 9 having been broken during observation.

[3] Magnetometer inductor 25 was thoroughly overhauled and minor repairs made during January 1915 in the instrument shop of the Department of Terrestrial Magnetism.

Terrestrial Magnetism; (5) radioactive content apparatus 4, provided with gimbal rings and mounting, water-dropping apparatus, direct-current motor, ionizing chamber, anemometer, and other appurtenances, designed and constructed for the most part by the Department of Terrestrial Magnetism. The designations adopted, respectively, for the 5 instruments are CA3, IC1, PRA1, PGA2, RCA4. (6) Accessories: Gerdien condenser, until April 1915; fiber electroscopes 12, 14, and 15, all constructed by the Department of Terrestrial Magnetism; Braun electroscope 1437; Wulf electroscopes 3537, 3995, and 4357, all by Günther and Tegetmeyer; Wiechert electroscope 2 by Spindler and Hoyer; high-resistance rheostats 1716 and 1751, from April 1916; batteries of cadmium cells and Eveready dry cells; Zamboni dry-piles 1449, until June 1915, and 3376, both by Günther and Tegetmeyer; voltmeters; volt-ammeter; potentiometer; gimbal stand; non-magnetic Gauss table; radium and ionium collectors; miscellaneous equipment, including non-magnetic clamps, special insulators, small tools, etc.

SEXTANTS, CHRONOMETERS, WATCHES, AND DIP-OF-HORIZON MEASURERS.

XL. *Sextants.* Same as for Cruise III with the addition of sextant L809 by John Bliss.

XLI. *Chronometers and watches.* (1) Marine chronometers same as for Cruise III, with the exception of Kittel 254 and 268; (2) watches 70 and 71 by the Hamilton Watch Company, 92 (sidereal) by the Waltham Watch Company, 106, 110, 116, and 117, all by the Elgin National Watch Company.

XLII. *Dip-of-horizon measurers.* (1) Dip-of-horizon measurer 4048 by Carl Zeiss; (2) micrometer dip-of-horizon measurer 4031 by Carl Zeiss, loaned by the United States Coast and Geodetic Survey until July 1915, designated as No. 1 of that survey; (3) dip-of-horizon measurer 5490 by Carl Zeiss.

METEOROLOGICAL INSTRUMENTS AND MISCELLANEOUS EQUIPMENT.

XLIII. *Meteorological instruments.* Same as for Cruise III,[1] with the exception of boiling-point apparatuses 3, 4, and 6, and thermometer Bureau of Standards number 4146, and with the addition of the following: (1) Boiling-point thermometers for work at sea, Bureau of Standards numbers 7828, 8119, and 8731; (2) special reading telescope and mounting for boiling-point work at sea, designed and constructed by the Department of Terrestrial Magnetism.

XLIV. *Miscellaneous equipment.* Same as for Cruise III, with the addition of the following: (1) experimental apparatus 1 for the determination of ship's motion, designed and constructed by the Department of Terrestrial Magnetism; (2) motion-picture camera and appurtenances.

GENERAL PROPERTY AND SUPPLIES.

Besides the instrumental equipment listed on pages 203–211, the general property and supplies on board the *Carnegie*, 1909–1916, in addition to what were necessary for the maintenance of the ship, were about as follows:

I. Navigation charts, maps, and atlases of various kinds.

II. Library of books on astronomy, navigation, magnetism (general and terrestrial), general physics, atmospheric electricity, general chemistry, meteorology, geography, geology, biology, sailing ship (sails and sail-making, etc.), encyclopedias, dictionaries, and general literature. The total number of books in the library is about 1,200, of which 1,000 relate to scientific and professional subjects. The library contains a complete set of the publications of the Carnegie Institution of Washington.

III. Medical books and miscellaneous supplies.

[1]Metric scales and verniers were added to the mercurial barometers 3948 and 4177 in February 1915.

SPECIMENS OF OBSERVATIONS AND COMPUTATIONS.

The following specimens of observations and computations, applying to the date August 23, 1913, will assist in making clear the methods followed on the *Carnegie*, and will serve to illustrate a typical day's observations at sea. The observing conditions will be found stated on the forms. The roll of vessel was about 4° starboard to 4° port; hence, the total roll, from side to side, was about 8°.

MAGNETIC OBSERVATIONS AND COMPUTATIONS.

Reference to the instructions for the magnetic work on Cruise II (pp. 317–322), and to the detailed description of methods followed in the *Galilee* work (pp. 33–57), will doubtless furnish the information required on any matter which may not be wholly understood from the forms themselves. Specimens illustrating shore work will be found in Volume I, pages 30–41. For specimen determinations of instrumental constants, see pages 234–250.

DECLINATION OBSERVATIONS, AUGUST 23, 1913.

Observations with marine collimating-compass.—Form 21*a*, page 213, illustrates the record of observations for magnetic declination made with the marine collimating-compass (C 1). The specimen gives the first 4 of 20 sets made during a period of 11 minutes by two observers, P and S. The scheme of observation calls for 5 sets by one observer, next 10 sets by the other observer, and finally, 5 sets again by the first observer. The mean results of the two observers are therefore comparable, referring as they do to the same time and to the same geographic position of ship. There are 10 readings in each set; hence, a complete determination by this one instrument consists of 200 readings. The times are noted by watch M, which requires a correction of $+9^h\,19^m\!.53$, as indicated in the portion headed "Chronometer Comparisons." It should be noted that the standard chronometer rate has been adjusted for sea rate, as was subsequently determined on arrival at the next port. Since this correction affects the longitude by precisely the same amount, the local apparent time of the original computation remains unaltered.

The scale readings have been taken in this specimen at exact intervals of 3 seconds, called out to the observer by the recorder. The observed angle between the Sun and scale, Δ_0, is corrected, if necessary, for index error to obtain Δ of the formula (6), page 181. The altitude of the Sun's estimated center, h_0, is measured by a third observer between the fifth and sixth readings of each set. An index correction, 0′, and the dip of the horizon, $-4'$ ($-0^\circ\!.07$), are applied to h_0 to obtain h of the formula.

The observed quantities or their means corrected as above stated are transferred to Form 26 or 26*a* for computation. Form 26 (p. 215) is used for low altitudes of the Sun, for then the approximate formula (6), page 181, and the corresponding tables are especially suitable. When, however, the Sun is so high that the interpolation becomes laborious or the limits of the tables are exceeded, then the alternative form (26*a*) is used. Examination of the latter form, of which a specimen is given on page 214 merely to illustrate the use of the rigorous formula for computing the angle A, shows that it is divided into two parts. The upper part contains the means of the observed quantities corrected and arranged in 4 groups of 5 sets, one group for each scale observed by each observer. The means of each group are then transferred to the places indicated in the lower part of the computation. The scale readings are reduced to center by subtracting 5 divisions from each and converting the results into degrees of arc. These quantities are then added algebraically to the scale constants, $+0^\circ\!.37$ and $180^\circ\!.31$, and carried down and entered at "constant + a" near the bottom of the form. From the values of m, h, and Δ the angle A is computed and applied directly to the values of "constant + a" by which operation the magnetic bearing of the Sun from south around by west is obtained. The astronomic azimuth is computed from any convenient azimuth tables with the arguments, Sun's declination, latitude, and local apparent time. The difference between this azimuth and the magnetic azimuth is the magnetic declination.

Ocean Magnetic Observations: Declination (*D*)

(Form 21a)

Station: At sea	*Lat:* 39° 44′ N	*Long:* 39° 50′ W
Date: Sat., Aug. 23, 1913, P. M.	*Vessel:* Carnegie	*Com'd'r:* W. J. P.
Compass: C1	*Obs'r:* P. and S.	*Rec'd'r:* N. M.
Weather: bc *Sea:* S	*Wind:* SSW, 2	*Roll:* 4° s. to 4° p.

Number	Set I: Course NNE, Time by Watch M	Set I: Scale N, Window 3	Set II: Course NNE, Time by Watch M	Set II: Scale N, Window 3
	h m s	*d*	*h m s*	*d*
1	8 49 51	4.0	8 50 21	6.0
2	54	6.2	24	4.0
3	57	3.8	27	6.1
4	50 00	5.5	30	4.1
5	03	4.0	33	5.9
6	06	5.1	36	4.5
7	09	5.0	39	5.2
8	12	3.7	42	5.0
9	15	5.9	45	4.8
10	50 18	4.2	48	5.2
Means	8 50 04	4.74	8 50 34	5.08
	$\Delta_0 = 55° 00'$; $h_0 = 5° 40'$		$\Delta_0 = 55° 00'$; $h_0 = 5° 35'$	

Number	Set III: Course NNE, Time by Watch M	Set III: Scale N, Window 3	Set IV: Course NNE, Time by Watch M	Set IV: Scale N, Window 3
	h m s	*d*	*h m s*	*d*
1	8 50 51	5.1	8 51 21	4.8
2	54	4.9	24	6.0
3	57	4.7	27	4.0
4	51 00	5.3	30	6.3
5	03	4.1	33	4.5
6	06	5.7	36	5.0
7	09	5.0	39	5.6
8	12	4.4	42	5.1
9	15	5.2	45	5.2
10	51 18	4.6	48	5.4
Means	8 51 04	4.90	8 51 34	5.19
	$\Delta_0 = 55° 00'$; $h_0 = 5° 30'$		$\Delta_0 = 55° 00'$; $h_0 = 5° 24'$	

Remarks

Magnetic articles removed: Yes
Large sextant used
Index correction to Δ_0: 0′
Index correction to h_0: 0′
Dip of horizon: 4′

CHRONOMETER COMPARISONS

	Before	After
	h m s	*h m s*
Chron. 53862	8 49 20	9 04 35
Corr'n on G. M. T.[1]	+12 00 41	+12 00 41
G. M. T.	20 50 01	21 05 16
E.	− 2 32	− 2 32
G. A. T.	20 47 29	21 02 44
Long.	− 2 39 20	− 2 39 20
L. A. T.	18 08 09	18 23 24
Watch M	8 48 37	9 03 52
Watch M on L. A. T.	+ 9 19 32	+ 9 19 32
Mean corr'n Watch M on L. A. T. $+9^h 19^m.53$		

[1] Adjusted for sea rate.

On Form 26 the means are entered and the values of a and "constant + a" are determined in exactly the same manner as on Form 26a. The angle A, however, is obtained by applying two corrections to the angle Δ, the first, designated "Tabular Reduction," being taken directly from Table 46, page 182, and the second, "Red'n of Scale to Horizon," is the product of the respective values of scale altitude and the factor obtained from Table 47.

Observations with sea deflector.—The observations of magnetic declination with the sea deflector (D4), made at the same time as those with the standard compass (C1), are shown in the specimen on Form 21a, page 215. In all, 20 sets of readings, similar to sets I, II, III, and IV given in the specimen, were taken. The computation is shown on Form 22, page 216. The various steps are made clear by the column-headings. The correction −0°.08, applied to the observed values of D, is derived from Table 55, page 236.

Computation of Declination Observations with Marine Collimating-Compass C1

(Form 26a)

Date: Sat., Aug. 23, 1913, P. M.
Scale constants: S, +0°.37; scale alt., −0°.17; scale val., 0°.98; N, +180°.31; scale alt., +0°.35; scale val., 0°.99; $Z = +0.453$ C.G.S.

Lat: 39° 44′ N
Vessel: Carnegie.
Obs'r: P. and S.
Sun's Decl'n: +11°.45

Long: 39° 50′ W
Com'd'r: W. J. P.
Comp'r: C. C. C.
Reviser: W. J. P.

Set No.	Window and scale: 3–N Obs'r: S				Set No.	Window and scale: 1–S Obs'r: P			
	L. A. T.	Scale reading	Δ	h		L. A. T.	Scale reading	Δ	h
	h m	d	°	°		h m	d	°	°
I	18 09.60	4.74	.....	5.60	VI	18 12.76	4.92	......	5.07
II	10.10	5.08	.....	5.52	VII	13.26	5.17	......	4.95
III	10.60	4.90	.....	5.43	VIII	13.76	5.05	......	4.85
IV	11.10	5.19	.....	5.33	IX	14.26	5.00	......	4.75
V	11.60	5.15	.....	5.23	X	14.76	5.55	......	4.67
Means	18 10.60	5.01	55.00	5.42	Means	18 13.76	5.14	125.50	4.86
	Window and scale: 3–N Obs'r: P					Window and scale: 1–S Obs'r: S			
	h m	d	°	°		h m	d	°	°
XI	18 15.86	5.45	.....	4.47	XVI	18 19.00	4.68	......	3.92
XII	16.36	5.67	.....	4.38	XVII	19.50	4.52	......	3.82
XIII	16.86	5.75	.....	4.30	XVIII	20.00	4.75	......	3.72
XIV	17.36	5.53	.....	4.22	XIX	20.50	4.74	......	3.62
XV	17.86	5.75	.....	4.15	XX	21.00	4.87	......	3.53
Means	18 16.86	5.63	54.50	4.30	Means	18 20.00	4.71	127.00	3.72

Set Number / Ship's Heading / Window and Scale	I to V / NNE / 3–N	VI to X / NNE / 1–S	XI to XV / NNE / 3–N	XVI to XX / NNE / 1–S
	h m	h m	h m	h m
L. A. T.	18 10.60	18 13.76	18 16.86	18 20.00
	d	d	d	d
Scale Reading	5.01	5.14	5.63	4.71
Scale −5.00	+0.01	+0.14	+0.63	−0.29
Reduction to Center = a	+0°.01	+0°.14	+0°.62	−0°.28
m = Scale Altitude	+0°.35	−0°.17	+0°.35	−0°.17
h	5.42	4.86	4.30	3.72
Δ	55.00	125.50	54.50	127.00
s	30.38	65.10	29.58	65.28
s–h	24.96	60.24	25.28	61.56
s–m	30.03	65.27	29.23	65.45
Log sin (s–h)	9.62530	9.93858	9.63047	9.94415
Log sin (s–m)	9.69936	9.95822	9.68870	9.95885
Log sec h	0.00195	0.00156	0.00122	0.00092
Log sec m	0.00001	0.00000	0.00001	0.00000
Log $\sin^2 \frac{1}{2} A$	9.32662	9.89836	9.32040	9.90392
A	−54°.85	+125°.64	−54°.43	+127°.09
Constant + a	180.32	0.51	180.93	0.09
Mag'c Azimuth	125.47	126.15	126.50	127.18
Astron. Azimuth	100.51	101.01	101.49	101.98
Magnetic Declination	−24.96	−25.14	−25.01	−25.20

Mean Magnetic Declination (*D*): −25°.08

Computation of Declination Observations with Marine Collimating-Compass C1

(Form 26)

Date: Sat., Aug. 23, 1913, P. M.
Scale constants: S, +0°.37; scale alt., −0°.17; scale val., 0°.98; N, +180°.31; scale alt., +0°.35; scale val., 0°.99; Z = +0.453 c.g.s.

Lat: 39° 44′ N
Vessel: Carnegie
Obs'r: P. and S.
Sun's Decl'n: +11°.45

Long: 39° 50′ W
Com'd'r: W. J. P.
Comp'r: C. C. C.
Reviser: W. J. P.

Set Number	I to V	VI to X	XI to XV	XVI to XX
Ship's Heading	NNE	NNE	NNE	NNE
Observer	H. R. S.	W. J. P.	W. J. P.	H. R. S.
Window and Scale	3–N	1–S	3–N	1–S
	h m	h m	h m	h m
L. A. T.	18 10.60	18 13.76	18 16.86	18 20.00
	d	d	d	d
Scale Reading	5.01	5.14	5.63	4.71
Scale Reading −5.00	+0.01	+0.14	+0.63	−0.29
Reduction to Center = a	+0°.01	+0°.14	+0°.62	−0°.28
Altitude, h	5.42	4.86	4.30	3.72
Angle to Sun, Δ	55°.00	125°.50	54°.50	127°.00
Tabular Reduction	−0.18	+0.15	−0.12	+0.09
Red'n of Scale to Horizon	+0.04	−0.02	+0.03	−0.01
A	−54°.86	+125°.63	−54°.41	+127°.08
Constant + a	180.32	0.51	180.93	0.09
Mag'c Azimuth	125.46	126.14	126.52	127.17
Astron. Azimuth	100.51	101.01	101.49	101.98
Magnetic Declination	−24.95	−25.13	−25.03	−25.19
Mean Magnetic Declination (D): −25°.08				

Ocean Magnetic Observations: Declination (D)

(Form 21a)

Station: At sea
Date: Sat., Aug. 23, 1913, P. M.
Compass: Defl'r 4 (D4)
Weather: bc *Sea:* S

Lat: 39° 44′ N
Vessel: Carnegie
Obs'rs: C. and H.
Wind: SSW, 2

Long: 39° 50′ W
Com'd'r: W. J. P.
Rec'd'rs: H. and C.
Roll: 4° s. to 4° p.

Number	Set I: Course NNE, Time by Chron. 256	Set I: Card Reading	Set II: Course NNE, Time by Chron. 256	Set II: Card Reading
	h m s	°	h m s	°
1	9 18 30	306.5	9 18 51	306.1
2		5.3		5.2
3		6.2		5.7
4		6.6		6.0
5		5.9		5.5
6		5.3		5.7
7		5.8		5.3
8		6.0		5.4
9		5.4		5.9
10	9 18 49	5.3	19 11	5.9
Means	9 18 40	305.83	9 19 01	305.67

Number	Set III: Course NNE, Time by Chron. 256	Set III: Card Reading	Set IV: Course NNE, Time by Chron. 256	Set IV: Card Reading
	h m s	°	h m s	°
1	9 19 13	305.5	9 19 37	305.7
......	......	......	......	......
10	9 19 35	5.3	19 57	5.7
Means	9 19 24	305.48	9 19 47	305.37

Remarks

Magnetic articles removed: Yes

CHRONOMETER COMPARISONS

	Before	After
	h m s	h m s
Chron. 53862	8 49 20	9 02 40
Corr'n on G. M. T.[1]	+12 00 41	+12 00 41
G. M. T.	20 50 01	21 03 21
E	− 2 32	− 2 32
G. A. T.	20 47 29	21 00 49
Long.	− 2 39 20	− 2 39 20
L. A. T.	18 08 09	18 21 29
Chron. 256	9 17 18	9 30 38
Chron. 256 on L. A. T.	+ 8 50 51	+ 8 50 51

Mean corr'n Chron. 256 on L. A. T. $+8^h50^m.85$

[1]Adjusted for sea rate.

Computation of Declination Observations with Sea Deflector D4

(Form 23)

Date: Sat., Aug. 23, 1913, P. M. *Lat:* 39° 44′ N *Long:* 39° 50′ W
Vessel: Carnegie *Obs'rs:* C. and H. *Comp'r:* C. C. C.
Com'd'r: W. J. P. *Sun's Decl'n:* +11°.45 *Reviser:* W. J. P.

Set No.	Time by Chron. 256	Local Apparent Time	Sun by Compass	Sun's Azimuth	Obs'd Decl'n D_0	Corr'n to D_0	Corr'd Decl'n D	Remarks
	h m	h m	°	°	°	°	°	
I	9 18.67		125.83					Obs'r, C. C. C.
II	19.02		5.67					
III	19.40		5.48					
IV	19.78		5.37					
V	20.17		5.61					
XVI	28.00		6.88					
XVII	28.27		7.04					
XVIII	28.58		7.00					
XIX	28.93		7.14					
XX	29.33		7.09					
Means	9 24.02	18 14.87	126.31	101.18	−25.13	−0.08	−25.21	
VI	9 21.97		125.66					Obs'r, C. W. H.
VII	22.30		5.73					
VIII	22.62		5.85					
IX	22.93		5.72					
X	23.27		6.07					
XI	24.73		6.43					
XII	25.03		6.08					
XIII	25.33		6.19					
XIV	25.63		6.23					
XV	25.97		6.27					
Means	9 23.98	18 14.83	126.02	101.17	−24.85	−0.08	−24.93	
Mean Magnetic Declination (D): −25°.07								

HORIZONTAL-INTENSITY OBSERVATIONS, AUGUST 23, 1913.

Specimen observations of horizontal intensity with sea deflector, D4, are given on form 24*b*, page 217. By consulting the "scheme of observations," page 194, the various entries will be readily understood. Sets I and II with magnet 45 at deflection distances 1 and 3 are recorded completely. Two similar sets, III and IV, were obtained with magnet 2L at deflection distances 1 and 3. The numbers attached to the readings for the deflector and the compass show the order in which the various readings were made in the respective columns; for numbers 1 to 5 the columns were filled from left to right, whereas, for numbers 6 to 10 the columns were filled from right to left. It will be observed that for each position prescribed in the scheme of observation, 5 settings were made, yielding in all 80 readings each for deflector and for compass. The 5 deflector-readings for distance U1, north end of magnet E, with corresponding compass-readings, were completed before passing to next position, etc.

When obtaining the means (1), it should be noted that, in accordance with the construction of the deflector, the quantity, 90°, is to be subtracted from readings for north end of magnet east, and added to the readings for north end of magnet west. The means (2) are the mean values of the 10 compass-readings in each column. The differences (3) result from subtraction of (2) from (1) for north end of magnet east, and (1) from (2) for north end of magnet west. Were the instrumental adjustments perfect, the differences (3) would be directly the deflection angles, u, affected alone by errors of observation. To eliminate outstanding defects of adjustment, the mean of the 4 differences, for each distance, is the final value of u.

Ocean Magnetic Observations: Horizontal Intensity (*H*)

(Form 24b)

Station: At sea
Date: Sat., Aug. 23, 1913, P.M.
Deflector: No. 4 (D4)
Course: NNE

Lat: 39° 29′ N
Vessel: Carnegie
Compass: No. 39670
Weather: bc

Long: 39° 51′ W
Com'd'r: W. J. P.
Chron'r: 256
Roll: 3° s. to 4° p.

Defl'r Obs'r: H. R. S.
Comp Obs'r: W. J. P.
Wind: S, 2
Sea: S to M

Magnet; Set	Mag. 45; Set I				Mag. 45; Set II				Vernier
Distance	U1	L1	L1	U1	U3	L3	L3	U3	
N. End Magnet	E	E	W	W	W	W	E	E	
	Deflector Readings								
Sight Line	L2 to 180°		L2 to 0°				L2 to 180°		
	°	°	°	°	°	°	°	°	
Reading 1	322.7	327.8	81.3	81.9	90.5	87.4	316.8	314.7	A
" 2	323.1	327.4	81.8	82.5	91.0	87.8	317.6	314.9	A
" 3	323.7	328.0	81.4	80.9	90.0	89.0	317.2	314.2	A
" 4	323.9	328.6	80.4	79.0	89.5	88.5	316.9	314.2	A
" 5	324.6	328.2	80.8	79.0	88.0	88.4	315.5	314.3	A
Sight Line	L2 to 0°		L2 to 180°				L2 to 0°		
	°	°	°	°	°	°	°	°	
Reading 6	323.2	327.2	76.6	78.5	88.0	85.4	314.9	313.4	B
" 7	326.0	329.1	77.2	78.3	86.8	86.2	314.9	317.0	B
" 8	326.5	329.6	79.1	77.4	88.6	87.9	313.9	318.0	B
" 9	326.7	329.1	81.9	77.8	88.8	88.2	313.3	316.9	B
" 10	325.5	329.0	83.4	78.3	90.0	89.0	313.3	317.3	B
(1) Means ∓ 90°	234.59	238.40	170.39	169.36	179.12	177.78	225.43	225.49	202°57
	Compass Readings								Means
	°	°	°	°	°	°	°	°	°
Reading 1	200.4	203.5	205.3	203.5	203.8	202.2	201.9	201.2	202.7
" 2	201.0	202.8	205.5	204.1	204.1	202.6	202.6	201.0	203.0
" 3	201.5	203.5	205.3	202.5	203.2	203.7	202.3	200.9	202.9
" 4	201.8	204.3	204.5	201.1	202.7	203.1	202.4	201.0	202.6
" 5	202.3	203.8	204.9	200.9	201.5	203.1	200.6	200.9	202.2
" 6	200.9	202.5	200.8	200.9	201.2	200.0	200.3	200.3	200.9
" 7	203.7	204.4	201.5	200.3	200.3	201.2	200.0	203.7	201.9
" 8	204.8	205.2	203.2	199.3	201.9	202.5	199.1	204.6	202.6
" 9	204.6	204.9	205.6	199.8	202.3	203.0	198.6	203.7	202.8
" 10	203.3	204.5	207.1	200.1	203.2	203.5	198.6	204.0	203.1
(2) Means	202.43	203.94	204.37	201.25	202.42	202.49	200.64	202.13	202°46
(3) Diff'r fr. 1 & 2	32.16	34.46	33.98	31.89	23.30	24.71	24.79	23.36	
Defl'n Angle, *u*	33°12				24°04				

Computations				
Set	I	II	III	IV
Mag. and Dist.	45, 1	45, 3	2L, 1	2L, 3
	h m	*h m*	*h m*	*h m*
L. M. T.	14 37	14 35	14 35	14 35
t	28°4	28°4	28°2	28°2
u	33°12	24°04	27°44	20°16
Log *mC*	9.0535	8.9275	8.9827	8.8556
Log sin *u*	9.7375	9.6100	9.6635	9.5374
Log *H*	9.3160	9.3175	9.3186	9.3182
H	0.2070	0.2077	0.2083	0.2081
Mean *H*	0.2078			

	Set I		Set II	
	Time	Temp.	Time	Temp.
	h m	°C	*h m*	°C
Beginning	5 09	28.4	5 16	28.4
Ending	6 18	28.4	6 08	28.4
Means	5 44	28.4	5 42	28.4
Corr'n 256	+8 53		+8 53	
L. M. T.	14 37		14 35	

Magnetic articles removed: Yes
Remarks: Vessel pitching about 2°
Computer: W. J. P.
Reviser: H. R. S.

The series of observations with magnet 2L at distances 1 and 3, similar to that with magnet 45, was made between the first half (first 40 readings, 1 to 5) of the observations with magnet 45 and the second half (second 40 readings, 6 to 10), or during the time, $5^h\ 25^m$ to $5^h\ 59^m$, as given by chronometer 256. During this period, magnet 45 was removed from the observing-house and stowed at a safe distance. The local mean times of observations with each magnet and for each distance, as will be seen from the computations, are the same within 2 minutes.

The computations of H are given in the lower part of the same form. The formula for computing H is given on page 236, and the values of log mC are obtained from Table 57, page 238. It will be seen that the 4 values of H (0.2070, 0.2077, 0.2083, 0.2081), resulting from the observations at two deflecting distances with magnets 45 and 2L, are in fair accord. The means in the last column give the mean readings of ship's heading during the observations. The mean (1) of the deflected card-readings for sea deflector 4 is 202°.57; the mean (2) of the direct readings with compass 39670 is 202°.46; the two independently derived mean readings of ship's heading thus differ only 0°.1. The mean reading of ship's heading, by deflector and compass, is 202°.5, which corresponds to the heading NNE, on which it was aimed to hold the vessel. A special form (25*a*), not given here, has also been devised for disclosing readily any defective readings of deflector or of compass.

A specimen determination of instrumental constants for the sea deflector will be found on page 240.

TOTAL-INTENSITY OBSERVATIONS, AUGUST 23, 1913.

Specimens of total-intensity observations and computations for August 23, 1913, with sea dip-circle 189, are shown in Form 28 (loaded-dip observations) and Form 28*a* (deflection observations), pages 219 and 220.

The scheme of observation consisted of set I, loaded dips, next deflections with both short and long distances, and finally set II of loaded dips. (See also p. 221.) It will be seen that, in the case of the loaded dips, the extreme positions taken by loaded needle, as it swings to and fro, are recorded[1] to the nearest degree. In the deflection observations it is necessary always to set the vertical thread of the microscope on middle of arc of swing of suspended needle. Only the deflection observations for short distance are given, the method of observing being the same for long distance. Before proceeding with the computation of the horizontal intensity, H, from the total-intensity observations, it is necessary to determine the adopted value of the inclination, I. At the bottom of Form 28*a*, p. 220, will be found a summary of the values of I, derived from the various observations (deflected dip, needle 7, short and long distances; regular dip, needles 5 and 9; earth-inductor dip). The adopted value of I, after the corrections on standard are applied, is +65°.20. This is used in getting the angle $u = I - I'$, and in the computations of H.

Referring to the formulæ on page 247, the methods of computing H from loaded dips and from deflections, given at bottom of form 28, page 219, will be readily understood. It will be seen that values of H are: 0.2084 (deflections, short distance), 0.2102 (deflections, long distance), and 0.2077 (loaded dips); the mean is 0.2088. The accord shown between the 3 values of H, derived from the total-intensity observations with the sea dip-circle, represents about the average case; sometimes the accord is considerably better, at other times worse. The mean value of H agrees with that derived from the sea-deflector observations to within 0.0010 C.G.S., which must be regarded as satisfactory.

[1]If arc of swing is too large for field of microscope, a hand magnifier is used. As the needle, owing to the ship's motions, is subject to discontinuous forces, causing sudden, spasmodic, and erratic displacements, it has not been found practicable to follow the scheme of observation for a rhythmic swing—combining, for example, two readings of extreme position on the right with one on the left, etc.

Ocean Magnetic Observations: Total Intensity (F by Loaded-Dip Method)

(Form 28)

Station: At sea	*Lat:* 39° 29′ N		*Long:* 39° 51′ W	*Obs'r:* C. C. C.
Date: Sat., Aug. 23, 1913, P. M.	*Vessel:* Carnegie		*Com'd'r:* W. J. P.	*Rec'd'r:* C. W. H.
Dip circle: D. C. 189	*Weather:* bc	*Sea:* S to M	*Chron'r:* 256	*Comp'r:* C. W. H.
Needle: 8 loaded; wt., 11	*Course:* NNE	*Wind:* S, 2	*Roll:* 3° s. to 4° p.	*Reviser:* C. C. C.

End of needle marked *A* north down — I

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
° °	° °	° °	° °	° °	° °	° °	° °
224 to 228	44 to 48	312 to 313	133 to 134	314 to 315	131 to 136	224 to 228	46 to 47
6 8	4 6	1 4	2 4	2 4	1 5	5 6	6 7
7 8	4 7	2 4	3 4	2 4	2 5	5 7	6 8
5 6	6 8	3 4	3 5	3 5	2 4	5 8	6 7
5 7	7 8	3 4	2 4	2 4	2 6	7 8	6 7
226°.4	46°.2	313°.0	133°.4	313°.5	133°.4	226°.3	46°.6
46°.30		46°.80		46°.55		46°.45	
46°.55				46°.50			

Mean I': +46°.52 $u = I - I' = +18°.68$

End of needle marked *A* north down — II

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
° °	° °	° °	° °	° °	° °	° °	° °
224 to 226	44 to 45	312 to 313	131 to 134	312 to 314	133 to 135	227 to 228	46 to 47
6 8	5 8	2 3	3 5	2 3	2 3	7 8	6 7
5 6	7 8	3 4	4 5	2 5	2 3	6 7	6 8
3 6	5 6	3 4	1 3	4 5	2 3	6 7	7 8
6 7	4 7	2 4	2 4	2 3	1 3	6 8	6 8
225°.7	45°.9	313°.0	133°.2	313°.2	132°.7	227°.0	46°.9
45°.80		46°.90		47°.05		46°.95	
46°.35				47°.00			

Mean I': +46°.68 $u = I - I' = +18°.52$

	Set I		Set II	
	Time	Temp.	Time	Temp.
	h *m*	°C	*h* *m*	°C
Beginning	5 18	28.8	6 02	29.2
Ending	21	8.8	04	9.4
Mean	5 20	28.8	6 03	29.3
L. M. T.	14 13	....	14 56	....

	h *m*
Chron'r 53862	4 36.0
Corr'n on G. M. T.	+12 00.7
G. M. T.	16 36.7
Long.	− 2 39.4
L. M. T.	13 57.3
No. 256 reads	5 03.9
No. 256 on L. M. T.	+ 8 53.4

Magnetic articles removed: Yes Gimbal circle reads: 22°.5; 202°.5

Computation of *H* from Deflections

Distance	Short		Long	
u_1	36°.48		25°.08	
Log csc u_1	0.2258		0.3728	
Log cos I	9.6227		9.6227	
Log C_4 at 29°.1 C.	9.4704		9.3271	
Log H	9.3189		9.3226	
H	0.2084		0.2102	

Computation of *H* from Loaded Dips

u	+18°.60	
Log csc u	0.4963	
Log cos (I' = +46°.60)	9.8370	
Log cos I	9.6227	
Log C_3 at 29°.0 C.	9.3614	
Log H	9.3174	
H	0.2077	

Ocean Magnetic Observations: Total Intensity (F by Deflection Method)

(Form 28a, reverse side of Form 28)

Station: At sea
Date: Sat., Aug. 23, 1913, P. M.
Dip circle: D. C. 189
Needle: 7 suspended; 8, deflecting
Weather: bc
Sea: S to M

Lat: 39° 29′ N
Vessel: Carnegie
Chron'r: 256
Course: NNE
Wind: S, 2
Roll: 3° s. to 4° p.

Long: 39° 51′ W
Com'd'r: W. J. P.
Obs'r: C. C. C.
Rec'd'r: C. W. H.
Comp'r: C. W. H.
Reviser: C. C. C.

End of suspended needle marked *A* north — **Distance: Short**

Circle East				Circle West			
Needle Face East				Needle Face West			
Micro. Direct		Micro. Reversed		Micro. Reversed		Micro. Direct	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
209.0	29.0	282.0	101.5	258.0	78.0	331.5	151.5
9.0	8.8	2.0	2.0	8.5	8.5	1.5	1.5
208°.95		281°.88		258°.25		331°.50	
65.42		36.46		36.62		65.12	

Mean *I*: +65°.27 Mean u_1: 36°.54

Suspended needle turned face about on bearings — **Distance: Short**

Circle West				Circle East			
Needle Face East				Needle Face West			
Micro. Direct		Micro. Reversed		Micro. Reversed		Micro. Direct	
S	N	S	N	S	N	S	N
°	°	°	°	°	°	°	°
330.8	150.2	258.0	78.0	281.0	101.0	208.0	28.5
1.2	0.5	8.0	8.0	1.0	1.5	8.0	8.0
330°.68		258°.00		281°.12		208°.12	
65.66		36.34		36.50		64.62	

Mean *I*: +65°.14 Mean u_1: 36°.42

Resulting Dip, *I*: +65°.20 Resulting Deflection-Angle, u_1: 36°.48

Time, Temperature, Remarks

	Time	Temp.
	h *m*	°C
Beginning	5 27	29.1
Ending	5 58	29.1
Means	5 42	29.1
L. M. T.	14 35	

Magnetic articles removed: Yes
Gimbal circle reads: 22°.5 and 202°.5

Summary of *I*-values, Aug. 23, 1916

Instr.	Needle	Observed *I*	Cor-rec'n	Corr'd *I*	Wt.
		°	°	°	
D. C. 189	7S	+65.20	+0.02	+65.22	1
D. C. 189	7L	+65.42	−0.10	+65.32	1
D. C. 189	5	+65.29	−0.07	+65.22	2
D. C. 189	9	+64.99	+0.08	+65.07	2
Weighted Mean				+65.19	
E. I. 3		+65.22	−0.02	+65.20	
Adopted *I*		....	....	+65.20	

INCLINATION OBSERVATIONS, AUGUST 23, 1913.

Observations with sea dip-circle.—Form 27, page 222 gives specimen inclination-observations by the direct or absolute method, using sea dip-circle 189, regular dip-needle 5, observing in all positions of circle and needle, inclusive of reversed polarity of needle.[1] Similar observations were made with needle 9. (For values by indirect method, see p. 218.)

The scheme of observing was: (1) dip with No. 5, *B* end down; (2) dip with No. 9, *B* end down; (3) loaded dip with needle 8; (4) deflections, short distance, first half; (5) deflections, long distance, first half; (6) deflections, long distance, second half; (7) deflections, short distance, second half; (8) loaded dip with No. 8; (9) dip with No. 9, *A* end down; (10) dip with No. 5, *A* end down.

As in the case of the loaded-dip observations, the extreme positions of the swinging dip-needle are recorded to nearest degree. For each extreme position, 5 readings are taken.

The results are given in the summary, bottom of Form 28*a*, page 220. The values of *I* by needles 5 and 9, referred to standard, are: +65°22 (No. 5) and +65°07 (No. 9). The mean, 65°14, agrees within 0°06, or 4′, with the earth-inductor value (+65°20).

Observations with marine earth-inductor.—Specimens of inclination observations and computations for August 23, 1913, with marine earth-inductor 3, are shown in Form 29 (earth-inductor observations) and Form 29*a* (galvanometer readings), pages 223 and 224.

The scheme of observation followed was as given on page 201. Galvanometer scale-readings similar to the specimen were made for each group of 4 vertical-circle (V. C.) settings, *i. e.*, for each position (*a*) commutator up with gimbal direct; (*b*) commutator down with gimbal direct; (*c*) commutator down with gimbal reversed; and (*d*) commutator up with gimbal reversed. There were thus 3 additional pages of galvanometer readings similar to the specimen for the complete specimen set of *I* with the earth inductor. The sequence of the additional galvanometer readings is indicated by the numbers in the columns headed "Settings" on the specimen Form 29. The galvanometer readings recorded under the heading *r* were made while the coil was spun by turning the crank mounted on the gimbal stand (see Pl. 14, Fig. 5) in right-hand direction; those recorded under the heading *l* were made while the coil was spun by turning the crank in left-hand direction. A second series of observations, set II, gave for the same station and date the following values for inclination: For commutator up with gimbal direct and reversed, +65°23; for commutator down with gimbal direct and reversed, +65°29; or a mean value of +65°26. The observed value obtained with the marine earth-inductor from sets I and II was therefore, +65°22, which reduced to standard is +65°20; the value obtained with sea dip-circle 189 at the same station is +65°19 (see p. 225).

The determination of the balance correction, *i. e.*, the correction on the vertical-circle setting, S_n, to obtain the vertical-circle setting for the plane of inclination, S_i, can be best shown by giving the computation of the corrections for vertical-circle settings S_1 and S_3 (see also p. 201):

$$\text{Correction on } S_1 = S_i - S_1 = \left(\frac{d_1}{d_1 - d_2}\right)(S_2 - S_1) = \left(\frac{-4.7}{-4.7 - 2.4}\right)(+2^\circ) = +1^\circ\!.32$$

$$\text{Correction on } S_3 = S_i - S_3 = \left(\frac{d_3}{d_3 - d_4}\right)(S_4 - S_3) = \left(\frac{-0.4}{-0.4 - 7.8}\right)(+2^\circ) = +0^\circ\!.10$$

The value for inclination follows immediately from S_i, bearing in mind that the vertical circle is graduated continuously from 0° to 360° in a clockwise direction, as one looks at the face of the circle. The verniers are fixed in position, while the circle bears a fixed relation to the rotation-axis of the inductor coil such that when the rotation-axis of the coil is horizontal the two vernier-readings are 0° and 180°.

[1]The reversal of polarity is made by means of a small electric coil, mounted in forward observing-dome, the magnetizing current being, of course, turned on only when no observations are being made.

Ocean Magnetic Observations: Inclination (I)

(Form 27)

Station: At sea	*Lat:* 39° 29′ N	*Long:* 39° 51′ W
Date: Sat., Aug. 23, 1913, P. M.	*Vessel:* Carnegie	*Com'd'r:* W. J. P.
Dip circle: D.C. 189	*Chron'r:* 256	*Obs'r:* C. C. C.
Needle: 5	*Course:* NNE	*Rec'd'r:* C. W. H.
Weather: bc	*Wind:* S, 2	*Comp'r:* C. W. H.
Sea: S to M	*Roll:* 3° s. to 4° p.	*Reviser:* C. C. C.

End of needle marked *B* down — Micro. A: Down

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
° °	° °	° °	° °	° °	° °	° °	° °
244 to 246	64 to 66	294 to 296	114 to 116	294 to 296	114 to 116	245 to 246	65 to 66
4 6	4 6	4 6	4 6	4 6	4 5	5 6	5 6
4 6	4 6	4 6	4 6	4 6	4 6	4 6	5 6
5 6	4 6	4 6	4 6	4 6	5 6	5 6	5 6
5 6	4 6	4 6	4 6	4 6	4 6	5 6	5 6
245°.2	65°.0	295°.0	115°.0	295°.0	115°.0	245°.4	65°.5
65°.10		65°.00		65°.00		65°.45	
65°.05				65°.22			

Mean: +65°.14

Polarities reversed. End of needle marked *A* down — Micro. A: Up

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
° °	° °	° °	° °	° °	° °	° °	° °
244 to 246	65 to 66	293 to 295	114 to 115	292 to 295	114 to 115	244 to 245	65 to 66
5 6	5 6	3 5	3 5	3 5	4 5	4 6	4 5
5 6	4 6	3 4	3 5	4 5	4 5	4 6	4 6
5 6	5 6	4 5	4 5	4 5	4 5	4 6	4 5
5 6	5 6	4 5	3 5	4 5	4 5	3 6	4 6
245°.4	65°.4	294°.1	114°.2	294°.2	114°.5	244°.8	64°.9
65°.40		65°.85		65°.65		64°.85	
65°.62				65°.25			

Mean: +65°.44

Resulting Dip, *I*: +65°.29

	h m		h m
Time of beginning by Chron'r 256	5 09	Chron'r 53862	4 36.0
Time of ending by Chron'r 256	6 18	Corr'n on G. M. T.	+12 00.7
		G. M. T.	16 36.7
Mean time by Chron'r 256	5 44	Long.	− 2 39.4
Corr'n of Chron'r 256 on L. M. T.	+8 53	L. M. T.	13 57.3
		No. 256 reads	5 03.9
Local mean time	14 37		
Magnetic articles removed: Yes		No. 256 on L. M. T.	+ 8 53.4
Gimbal circle reads: 22°.5 and 202°.5			

Ocean Magnetic Observations: Earth-Inductor Observations for Inclination (I)

(Form 29)

Station: At sea
Date: Sat., Aug. 23, 1913, P. M.
Instrument: E. I. 3; Galv'r M1
Horizontal circle: 180°; 0°
Gimbal circle: 22°; 202°
Revolutions of crank per minute: 120

Lat: 39° 29′ N
Vessel: Carnegie
Chron'r: 256
Weather: bc
Sea: S to M
Course: NNE
Wind: S, 2

Long: 39° 51′ W
Com'd'r: W. J. P.
Obs'r: C. W. H.
Rec'd'r: H. R. S.
Comp'r: C. C. C.
Reviser: C. W. H.
Roll: 4° s. to 5° p.

[1]Correction = $\left(\frac{d_n}{d_n - d_{n+1}}\right)\Delta$; see Form 29a for values of d.

Ocean Magnetic Observations: Earth-Inductor Observations (Galvanometer Readings)

(Form 20a)

Station: At sea
Date: Sat., Aug. 23, 1913, P. M.
Instrument: Galv'r M1
Shunt: 100 *Watch:* M

Lat: 39° 29′ N
Vessel: Carnegie
Obs'r: C. C. C.
Comp'r: C. C. C.

Long: 39° 51′ W
Com'd'r: W. J. P.
Rec'd'r: N. M.
Reviser: C. W. H.

V. C. of Inductor	East				West			
V. C. Setting	1		2		3		4	
Crank Turn	*r*	*l*	*r*	*l*	*r*	*l*	*r*	*l*
	d	*d*	*d*	*d*	*d*	*d*	*d*	*d*
Scale Reading 1	56	62	53	56	56	59	61	54
" " 2	58	61	59	56	57	58	62	59
" " 3	58	62	68	59	59	59	63	56
" " 4	59	59	64	58	56	61	65	54
" " 5	56	58	62	57	59	62	64	57
" " 6	56	66	63	56	66	61	61	58
" " 7	57	62	61	59	62	59	64	53
" " 8	58	59	61	61	58	59	66	58
" " 9	58	63	58	57	66	59	63	56
" " 10	56	61	56	56	66	61	61	57
Means, 1 to 10	57.2	61.3	60.5	57.5	60.5	59.8	63.0	56.2
Scale Reading 11	59	62	59	58	63	62	64	54
" " 12	58	64	69	62	54	62	69	56
" " 13	59	62	66	61	56	61	66	57
" " 14	56	62	62	58	59	60	63	55
" " 15	54	61	57	57	62	60	66	56
" " 16	57	66	59	59	61	62	66	54
" " 17	58	64	62	62	58	61	62	56
" " 18	59	61	61	59	62	59	62	57
" " 19	56	61	59	58	61	58	61	56
" " 20	54	61	58	59	54	59	66	58
Means, 11 to 20	57.0	62.4	61.2	59.3	59.0	60.4	64.5	55.9
Means, 1 to 20	57.1	61.8	60.8	58.4	59.7	60.1	63.8	56.0
Differences, $r-l$	*d* $-4.7=d_1$		*d* $+2.4=d_2$		*d* $-0.4=d_3$		*d* $+7.8=d_4$	
	h m	*h m*	*h m*	*h m*	*h m*	*h m*	*h m*	*h m*
Time, Beginning	4 15.1	4 15.5	4 16.3	4 16.7	4 17.6	4 18.0	4 18.9	4 19.3
Time, Ending	15.4	15.8	16.6	17.0	18.0	18.3	19.2	19.6
Mean Watch Times	4 15.2	4 15.6	4 16.4	4 16.8	4 17.8	4 18.2	4 19.0	4 19.4

Mean Watch Time for Galv'r Readings for V. C. Settings 1 to 4	4 17.3
Watch Correction on Local Mean Time[1]	+9 22.1
Local Mean Time for Galv'r Readings for V. C. Settings 1 to 4	13 39.4

[1]Obtained from page 213 by applying the equation of time.

SUMMARY OF MAGNETIC OBSERVATIONS ON AUGUST 23, 1913.

There have been included in the following summary of results of magnetic observations made in the afternoon of August 23, 1913, also the declination observations in the morning of the same day at station 1336 C II.

TABLE 51.—*Results of Magnetic Observations on August 23, 1913.*

Station	Latitude	Long. East of Gr.	Declination					Inclination					Horizontal Intensity				
			L.M.T.	Value	Inst.	Obs'r	p[4]	L.M.T.	Value	Instr.	Obs'r	p[4]	L.M.T.	Value	Instr.	Obs'r	p[4]
	° ′	° ′	h	°				h	°				h	c. g. s.			
1336 C II[1]	38 48 N	320 10	5.6	24.16 W	C1[5]	P&S	2										
			5.5	24.06 W	D4[6]	C&H	1										
	Weighted mean			24.13 W (24°08′W)													
1337 C II[2]	39 29 N	320 09						14.6	+65.19	189.5978[7]	CCC	1	14.6	.2078	D4[8]	HRS	3
								14.7	+65.20	EI 3[8]	CWH	1	14.6	.2093	189.75SL[9]	CCC	2
														.2077	189.8[10]	CCC	1
					Weighted means				+65.20 (+65°12′)					.2083			
1338 C II[3]	39 44 N	320 10	18.3	25.08 W	C1[5]	P&S	2										
			18.3	25.07 W	D4[6]	C&H	1										
	Weighted mean			25.08 W (25°05′W)													

[1]Course, NNE; roll from side to side, 6°; sea, S; weather, bc.
[2]Course, NNE; roll from side to side, 8°; sea, MS; weather, bc.
[3]Course, NNE; roll from side to side, 8°; sea, S; weather, bc.
[4]This is the combining weight when taking the weighted mean of individual values. It is not to be confused with the "weight" (wt.) which appears in the Table of Results. The latter is intended to give an approximate measure of the reliability of a result according to conditions encountered. Thus, to the results on August 23, 1913, a weight of 3 was assigned in the table. (See explanation, pp. 258–259.)
[5]Marine collimating-compass 1.
[6]Sea deflector 4.
[7]Sea dip-circle 189, regular dip needles 5 and 9, and intensity needle 7 deflected by intensity needle 8; for summary of individual values, see bottom of Form 28a, p. 220.
[8]Marine earth-inductor 3.
[9]Sea dip-circle 189, deflection observations with needles 7 and 8.
[10]Sea dip-circle 189, loaded-dip observations with needle 8.

GEOGRAPHIC POSITIONS AT SEA.

In ordinary navigation the position of the ship is required at the earliest moment possible, particularly in the vicinity of land, rocks, reefs, and like dangers. For this purpose a single Sumner line is often sufficient for the immediate needs of the navigator. For the geographic positions of sea-stations, where magnetic results have been obtained, the promptness of acquiring the geographic coordinates is not so important as the attainment of the highest precision, which necessarily involves delay to secure the data and make additional computations. The navigational work of the *Carnegie* has been planned to meet both requirements. The dead-reckoning is advanced as quickly as is practicable, and the new navigational methods are freely used when advantageous, but upon the high seas the usual work of navigation on the *Carnegie* is computed on forms which become a permanent record, and permit application of subsequent corrections for current effects or similar causes that may affect the course and distance run.

DEAD RECKONING.

The data for the dead reckoning (D. R.) are the ship's courses and the log-readings, the corrections to these, the astronomic positions, and the times or places for which positions are required. The times, places, courses, leeway, and log-readings are taken from the ship's log-book and entered on Form 42 below. In the column headed "Ship's Time" are entered the ship's times at the various places whose geographic positions are required, either for scientific results or for navigational reasons. The places are stated or else indicated by symbols or abbreviations, which will readily be recognized. The first entry refers to the last position of the day before. In the specimen form it is the place where two-star observa-

Geographic Positions at Sea: Dead Reckoning

(Form 42)

Date: Sat., Aug. 23, 1913 *Wind:* SSE, SE, S, SSW *Comp'r:* H. R. S.
Vessel: Carnegie *Com'd'r:* W. J. P. *Reviser:* W. J. P.

Ship's Time	Compass	Decl'n	Dev'n	Leeway	True Course	Log Readings	Distances	N	S	E	W	Diff. Long.
h m	°	°	°	°	°		miles	'	'	miles	miles	'
7 04 p. m., ** yesterday						31.2						
5 38 a. m., *D* obs'ns	N 22 E	−24	0	0	358	83.4	52.2	52.2	.....	.....	1.8	2.3 W
8 03 a. m., ⊙ alt.	N 22 E	−24	0	0	358	94.8	11.4	11.4	.....	.....	0.4	0.5 W
9 18 G. M. Noon	N 22 E	−24	0	0	358	100.8	6.0	6.0	.....	.....	0.2	0.3 W
Noon	N 22 E	−24	0	0	358	13.8	13.0	13.0	.....	.....	0.4	0.5 W
2 42, *H* and *I* obs'ns	N 22 E	−25	0	0	357	25.9	12.1	12.1	.....	.....	0.6	0.8 W
4 00, ⊙ alt.	N 22 E	−25	0	0	357	31.3	5.4	5.4	.....	.....	0.3	0.4 W
6 20, *D* obs'ns	N 22 E	−25	0	0	357	40.6	9.3	9.3	.....	.....	0.5	0.7 W
7 06, ** alt.	N 22 E	−25	0	0	357	44.1	3.5	3.5	.....	.....	0.2	0.3 W

	h m	Latitude ° '	Longitude[1] ° '		h m	Latitude ° '	Longitude[1] ° '
Yesterday at	7 04 p. m.	37 59.0 N	39 46.9 W	By D. R.	2 42 p. m.	39 28.9 N	39 50.3 W
Run to *D* obs'ns	5 38 a. m.	52.2 N	02.3 W	Run to ⊙ alt.	4 00 p. m.	05.4 N	00.4 W
By D. R.	5 38 a. m.	38 51.2 N	39 49.2 W	By D. R.	4 00 p. m.	39 34.3 N	39 50.7 W
(Adjusted)	5 38 a. m.	(38 48.2 N)	(39 48.4 W)	(Adjusted) by obs.	4 00 p. m.	(39 34.7 N)	39 50.1 W
Run to ⊙ alt.	8 03 a. m.	11.4 N	00.5 W	Run to *D* obs'ns	6 20 p. m.	09.3 N	00.7 W
By D. R.	8 03 a. m.	39 02.6 N	39 49.7 W	By D. R.	6 20 p. m.	39 43.6 N	39 50.8 W
(Adjusted) by obs.	8 03 a. m.	(38 58.9 N)	39 48.7 W	(Adjusted)	6 20 p. m.	(39 44.2 N)	(39 49.1 W)
Run to G. M. Noon	9 18 a. m.	06.0 N	00.3 W	Run to ** alt.	7 13 p. m.	03.5 N	00.3 W
By D. R.	9 18 a. m.	39 08.6 N	39 49.0 W	By D. R.	7 13 p. m.	39 47.1 N	39 51.1 W
(Adjusted)	9 18 a. m.	(39 04.6 N)	(39 48.9 W)	By obs.	7 13 p. m.	39 47.8 N	39 48.8 W
Run to	Noon	13.0 N	00.5 W				
By D. R. at	Noon	39 21.6 N	39 49.5 W				
By obs. (adjusted)	Noon	39 16.8 N	(39 49.2 W)				
Run to *HI* obs'ns	2 42 p. m.	12.1 N	00.8 W				
By D. R. at	2 42 p. m.	39 28.9 N	39 50.3 W				
(Adjusted)	2 42 p. m.	(39 29.2 N)	(39 49.8 W)				

[1] Longitudes are to be increased by 1'.4 on account of sea rate of chronometer, determined finally, September 12, 1913.

tions made in the evening of August 22 have determined both latitude and longitude. The ship's magnetic courses by the standard compass are entered in the second column under "compass." The magnetic declinations given in the next column are taken from navigation charts corrected, as necessary, for the error indicated by the magnetic results of preceding days; the minus sign indicates west declination. The deviation at the standard compass is zero, as noted in the fourth column. The leeway is taken from the log-book, where its estimated magnitude is recorded every 4 hours, or at every change of wind or course. In the specimen form, the wind coming from SSE to SSW and the

ship heading N 22° E, there is no leeway. The true course is the compass course corrected for the foregoing, and is entered in the column under "True Course"; it is counted from north as zero, through east, continuously to 360°. The readings of the log and their differences, or the distances in miles, are given in the next two columns. Under the letters N, S, E, and W, is the ordinary form for computing latitude and departure. The departures are converted into minutes of longitude and placed in the last column.

The lower portion of Form 42 contains the geographic positions and the latitude and longitude increments due to the vessel's run, taken from the final columns of the upper portion of the form. Here, also, the first entry is the last position of the day before. The various increments of latitude and longitude are transferred to their proper places as soon as they become available, and the vessel's approximate position is therefore practically always known by carrying on the summations. As soon as they become available the astronomic positions are written in after the words "By obs." The adjusted values are also written on the same line, but are distinguished from the astronomic positions by inclosing them in parentheses. As the adjusted positions are not inserted on the form before the dead reckoning has been made, they do not interfere with the legibility of original computation.

The positions of the various magnetic stations at sea are adjusted for the discrepancies that are usually found between the dead-reckoned and the astronomic determinations that immediately follow them. Since the latitude and longitude are rarely obtained simultaneously except at twilight, they must be adjusted separately and between different control observations. Thus in the specimen Form 42, starting from the star determination at $7^h\ 04^m$ of the evening of August 22, it will be seen that there is no control over the dead-reckoned latitudes before the noon observations. The noon position by dead reckoning is 39° 21!6 N, and by observation it is 39° 16!8 N. The difference, 4!8, is distributed proportionally to the elapsed time, so that the dead-reckoned latitude of the morning declination station, made at $5^h\ 38^m$, is to be decreased from 38° 51!2 N to 38° 48!2 N. Similarly, the longitude of the same magnetic station is adjusted by decreasing its dead-reckoned longitude from 39° 49!2 W to 39° 48!4 W by distributing the difference, 1!0, between the dead-reckoned longitude and the observed longitude at $8^h\ 03^m$ in the morning, proportionally to the time elapsed since $7^h\ 04^m$ of the evening before.

The position of the observations of magnetic dip and horizontal intensity, made at $2^h\ 42^m$ in the afternoon, is adjusted for latitude between the noon position and the two-star position obtained at $7^h\ 15^m$ in the evening, and for longitude between the morning astronomic longitude at $8^h\ 03^m$ and the afternoon longitude at $4^h\ 00^m$. The longitudes require a further correction, as indicated in the footnote of the form. This correction, however, can not be determined before the next port is reached, where standard time is available for controlling the chronometer rates, which have to be assumed, in the meantime, as being the same as determined at the last port. This longitude correction in the specimen Form 42 depends upon the chronometer corrections determined at St. Helena June 24, 1913, and again at Falmouth September 12, 1913, that is, from a period of 80 days. With the corrections determined at St. Helena and the adopted rates while at sea, the computed Greenwich mean time was found to be 7ˢ3 slow on the standard at Falmouth. Therefore the correction to the longitudes of August 23, 1913, expressed in minutes of arc, is

$$\frac{7.3}{4} \times \frac{60}{80} = 1'\!.4, \text{ increasing west longitudes.}$$

The final geographic positions of magnetic stations on August 23, 1913, are, therefore 38° 48′ N and 39° 50′ W for morning magnetic-declination results; 39° 29′ N and 39° 51′ W for magnetic intensity and dip results; and 39° 44′ N and 39° 50′ W for the afternoon magnetic-declination results, as appear on the magnetic-observation sheets of this date.

LONGITUDE OBSERVATIONS (SINGLE ALTITUDES).

Specimen observations and computations of astronomic longitudes by single altitudes are shown on Form 41 below, which is designed for both Sun and star altitudes, the portions not required in either case being marked in the specimen form "for star observations," or "for Sun observations." The hour angle, t, is computed from the latitude φ, the polar distance p, and the altitude h, by means of the equation

$$\sin^2 \frac{1}{2} t = \sec \varphi \operatorname{cosec} p \cos s \sin (s - h)$$

in which $s = \frac{1}{2}(h + \varphi + p)$. Six altitudes are measured in quick succession, three of the lower limb and three of the upper limb when the Sun is observed, as indicated in the specimen form. The times are noted by a recorder who enters them with the corresponding

Geographic Positions at Sea: Longitude Observations (Single Altitudes)

(Form 41)

Date: Sat., Aug. 23, 1913, A. M. *Vessel:* Carnegie *Com'd'r:* W. J. P.
Watch: M *Obs'r:* H. R. S. *Comp'r:* H. R. S.

altitudes. In the specimen above the times were taken from the watch M, which had been compared with the chronometer 53862, the entries being made in the allotted space on the form at the time the comparisons were made. Greenwich mean time is indicated by the letters G. M. T. The right ascension of the mean Sun, Greenwich sidereal time, the right ascension, the hour angle, and equation of time are indicated respectively by the abbreviations R. A. M. S., G. S. T., R. A., t, and E. "Tab. III" refers to the table of the American Ephemeris which gives the acceleration of sidereal on mean time. With these explanations the steps of the computation are easily followed to the longitude.

The computation has been made with an approximate latitude 39° 02′.6 N, which was taken from the dead reckoning. This latitude was adjusted later, as has been explained, and consequently the resulting longitude required a correction for the change of latitude, 3′.7 south. This change is computed from the well-known differential formula or taken from any one of the numerous nautical tables designed for the purpose. The specimen given is one of two sets. The other, having been made and computed independently by another observer, gives a corrected longitude of 39° 48′.4 W. The mean, 39° 48′.7 W, is the adopted value finally entered on the dead-reckoned sheet after the words "By obs."

LATITUDE OBSERVATIONS.

The latitude observations are recorded and computed on Form 40, of which a specimen is given below. According to the usual practice at sea, the maximum altitude of the Sun is noted at noon. The specimen shows the observations made at noon on August 23 by three observers, C. C. C., H. R. S., and M. C. The mean of three, 39° 16′.8 N, is adopted and entered in the dead reckoning.

The longitude is again determined in the afternoon by two observers in the manner already shown (Form 41, p. 228). The results by two observers are 39° 49′.5 W and 39° 50′.7 W, the mean of which, 39° 50′.1 W, has been entered in the appropriate place of the dead-reckoning sheet.

Geographic Positions at Sea: Latitude Observations

(Form 40)

Date: Sat., Aug. 23, 1913 *Vessel:* Carnegie *Com'd'r:* W. J. P. *Obs'rs and Comp'rs:* C. C. C., H. R. S., M. C.

Observer	Sextant No.	Object	Obs'd Alt. °	′	″	Index Corr'n ′	″	Alt. Corr'd for I. C. °	′
C. C. C.	22876	☉	62	05	00	−1	00	62	04.0
H. R. S.	2617	☉	62	04	20	0	00	62	04.3
M. C.	2611	☉	62	01	30	+2	30	62	04.0
						Mean		62	04.1
						Total corr'n			+11.3
						True alt.		62	15.4
						Zen. dist.		27	44.6
						Decl'n		+11	32.2
						Latitude (N)		39	16.8

Sextant No.	Observations for Index Corr'n (Sun's diameter) ′	″	′	″
22876	−32	40	+30	40
2617	31	40	31	40
2611	29	10	34	10

Corrections	′
Semi-Diam.	+15.9
R. & P.	− 0.4
Dip	− 4.2
Total	+11.3

Declination calculation	°	′
Decl'n at G. M. N.	+11	34.5
Hourly Diff.: −0′.85		
Time from G. M. N.: +2ʰ.7		
Corr'n: (+2.7)(−0.85)		−02.3
Decl'n at Obs'n	+11	32.2

Remarks	
Position: bridge	Thermometer: 26°.5 C.
Height of eye: 18 feet	Starb. log: 13.8
Horizon: good	Port log: ——
Wind: S 2	Dir. of object: S
Barometer: 772 mm.	

LATITUDE AND LONGITUDE OBSERVATIONS (TWO-STAR ALTITUDES).

The astronomic work of the day is finally completed by two-star observations, both of which are recorded and computed on Form 41*a*, which is practically the same as Form 41, already described. When one of the observations, however, is a meridian altitude, then latitude form (No. 40 above) is used. In the specimen (p. 230), the observations on Arcturus and Jupiter by one of the two observers, together with the computations, are shown. The dead-reckoned latitude, 39° 47′.1 N, was used in the computations; the correction to this latitude is +0′.7, making a final value of 39° 47′.8 N, as obtained from differential formulæ or from nautical tables. The approximate correction $\Delta\varphi$, by differential formulæ is obtained from the equation

$$\Delta\varphi = \frac{\lambda' - \lambda''}{\cot A'' - \cot A'} \cos\varphi$$

in which λ' and λ'' are the approximate longitudes (reckoned westward), determined respectively from the separate stars, by using an assumed latitude, φ, while A' and A'' are the respective azimuths reckoned positive from south around by west.

Geographic Positions at Sea: Latitude and Longitude Observations (Two-Star Altitudes)

(Form 41a)

Date: Sat., Aug. 23, 1913, P. M. *Vessel:* Carnegie *Com'd'r:* W. J. P. *Obs'r:* H. R. S. *Computer:* H. R. S.

Object	Time by Watch M	Observed Altitude		Chronometer Comparisons Before	Chronometer Comparisons After
	h m s	° ′		h m s	h m s
Arcturus	9 45 56	46 09.5	Chron'r 53862	9 04 35.0	9 58 25.0
	46 27	46 04.0	Chron'r corr'n	+36.5	+36.5
	46 48	46 00.5	G. M. T.	9 05 11.5	9 59 01.5
	47 05	45 57.0	Watch M	9 03 52.0	9 57 41.6
	47 28	45 52.0			
	47 53	45 47.5	Watch M corr'n	+01 19.5	+01 19.9
Means	9 46 56.2	45 58.4	Starb'd log		
Corrections	+01 19.8	−01.9	Port log		
G. M. T.	9 48 16.0	45 56.5	= True *h*		
R. A. M. S.	10 04 41.3	39 47.1	= *φ*	Log sec *φ*	0.11438
Tab. III	01 36.6	70 22.0	= *p*	Log csc *p*	0.02601
G. S. T.	19 54 33.9	156 05.6	= 2 *s*		
R. A. of star	14 11 43.1	78 02.8	= *s*	Log cos *s*	9.31621
H. A. from Gr.	5 42 50.8	32 06.3	= (*s*-*h*)	Log sin (*s*-*h*)	9.72548
				Log sin² ½*t*	9.18208

Sex. No. 2944

Corrections to Obs. Alt.	′
Semi-diameter	......
Refraction and Par.	−0.9
Dip of horizon	−3.5
Index corr'n	+2.5
Eccentricity	......
Total	−1.9

Corr'd latitude: 39° 47′.8 N

	h m s
t	3 03 37.5
H. A. from Gr.	5 42 50.8
Longitude in time	2 39 13.3
Longitude in arc	39° 48′.3
Corr'n for ass'd lat. (+0′.7) (+0.3)	+00.2
Corr'd longitude	39 48.5

Astronomic Elements	
	° ′
Decl'n at G. M. N.	+19 38.0
Hourly diff.: 0′.0	
Time from G. M. N.: +9h.8	
Corr'n: (+9.8)(0.0)	0.0
Decl'n at obs'n	+19 38.0
Eq. time at G. M. N.	for Sun obs'ns
Hourly diff.:	
Time from G. M. N.:	
Correction:	
Eq. time at obs'n	
	h m s
R. A. of star at G. M. N.	14 11 43.1
Hourly diff.: 0s.0	
Time from G. M. N.: +9h.8	
Corr'n: (+9.8)(0.0)	00.0
Right asc'n at obs'n	14 11 43.1

Remarks

Position: quarter-deck
Ht. of eye: 13 ft. Horizon: good
Wind: SSW Bar.: 772 mm.
Thermometer: 24°.4 C.
Direc. of obj.: N 103° W

Object	Time by Watch M	Observed Altitude		Chronometer Comparisons Before	Chronometer Comparisons After
	h m s	° ′		h m s	h m s
Jupiter	9 53 26	24 31.5	Chron'r 53862	9 04 35.0	9 58 25.0
	54 07	34.5	Chron'r corr'n	+36.5	+36.5
	54 28	36.5	G. M. T.	9 05 11.5	9 59 01.5
	54 48	38.5	Watch M	9 03 52.0	9 57 41.6
	55 06	39.5			
	55 25	40.5	Watch M corr'n	+01 19.5	+01 19.9
Means	9 54 33.3	24 36.8	Starb'd log 44.1		
Corr'ns	+01 19.9	−03.1	Port log.......		
G. M. T.	9 55 53.2	24 33.7	= True *h*		
R. A. M. S.	10 04 41.3	39 47.1	= *φ*	Log sec *φ*	0.11438
Tab. III	+01 37.9	113 23.7	= *p*	Log csc *p*	0.03726
G. S. T.	20 02 12.4	177 44.5	= 2 *s*		
R. A. of star	18 35 51.8	88 52.2	= *s*	Log cos *s*	8.29492
H. A. from Gr.	1 26 20.6	64 18.5	= (*s*-*h*)	Log sin (*s*-*h*)	9.95479
				Log sin² ½*t*	8.40135

Sex. No. 2944

Corrections to Obs. Alt.	′
Semi-diameter	......
Refraction and Par.	−2.1
Dip of horizon	−3.5
Index corr'n	+2.5
Eccentricity	......
Total	−3.1

Corr'd latitude: 39° 47′.8 N

	h m s
t	1 13 04.1
H. A. from Gr.	1 26 20.6
Longitude in time	2 39 24.7
Longitude in arc	39° 51′.2
Corr'n for ass'd lat. (+0′.7) (−4.0)	−02.8
Corr'd longitude (West)	39 48.4

Astronomic Elements	
	° ′
Decl'n at G. M. N.	−23 23.6
Hourly diff.: −0′.01	
Time from G. M. N.: +9.9	
Corr'n: (+9.9)(−0.01)	−0.1
Decl'n at obs'n	−23 23.7
Eq. time at G. M. N.	for Sun obs'ns.
Hourly diff.:	
Time from G. M. N.:	
Corr'n:	
Eq. time at obs'n	
	h m s
R. A. of star at G. M. N.	18 35 55.9
Hourly diff.: −0s.41	
Time from G. M. N.: +9h.9	
Corr'n: (+9.9)(−0.41)	−04.1
Right asc'n at obs'n	18 35 51.8

Remarks

Position: quarter-deck
Ht. of eye: 13 ft. Horizon: good
Wind: SSW Bar.: 772 mm.
Thermometer: 24°.4 C.
Direc. of Obj.: N 162° E

If the two-star observations are not simultaneous, the first observation is usually referred to the second by applying a correction to altitude of the first. This correction, expressed in minutes of arc, is equal to the number of nautical miles run, multiplied by the cosine of the angle between the ship's course and the direction of the first star. This correction is negligible in the specimen on the preceding page.

The adopted results derived from the observations of the two observers are latitude 39° 47ʹ.8 N and longitude, 39° 48ʹ.8 W, which are entered on the dead-reckoning sheet (Form 42). The positions depending on the dead reckoning alone may then be adjusted for the day, as has been described. The final values are used to the nearest minute.

It is realized that the discrepancies between the dead-reckoned and the astronomic positions may be owing to causes that do not operate uniformly over the time during which the errors are distributed, and that the discrepancies are also partly because of observational errors. But in the absence of information to the contrary, the assumptions of observational errors and of uniform changes are the only ones admissible. The specimens have been selected at random and represent usual conditions. Larger discrepancies are often found which are ascribed, in most cases, to the effects of ocean currents.

ACCURACY OF POSITIONS AT SEA.

The remarks on this matter in connection with the *Galilee* work (see page 59) apply likewise to the *Carnegie* work. With slight modifications, they are repeated here.

Accuracy of geographic positions is dependent on so many factors that it is quite impossible to define it by exact figures based on any one investigation of numerical results. The first consideration would naturally be the magnitude of the probable error of the measured altitudes, and if the observation were a meridional one, this probable error would be the probable error of the resultant latitude at the instant of observation. But as it rarely happens that this instant corresponds to the time of a magnetic observation, the observed latitude must be altered by a quantity which depends upon the run of the ship between observed latitude and the place of the magnetic observations.

The error in run may be controlled by the astronomic observations immediately preceding and following the magnetic observations. This procedure is, in fact, the method employed in the ocean work. But in attempting to assign limits of accuracy we are again confronted with the error in this control which depends upon the stability of the speed and direction of the ocean currents, the constancy of the leeway, steering, and error of the log. Again, if the observed Sun or star be east or west of the meridian, there is an additional uncertainty introduced by the unknown error in the assumed chronometer rate. This error, however, is very small in the case of our work, since it is controlled by time comparisons at every port available for the purpose, and is distributed back when appreciable. An investigation of some of the determinations of ship's position by simultaneous observations on three stars indicates that, if the Sun or star be favorably situated and the weather and sea conditions are fair, the average error to be expected in the determination of geographic position is less than 2 miles. The error in the control of the "error of run" is usually insignificant if the controlling astronomic observations are not more than 6 hours apart. This has usually been the case in our observations, except in high latitudes, where fog and clouds prevail. Of course, there are exceptional times when no astronomic observations are possible for several days. The geographic positions for the results of magnetic inclination and intensity are then more or less uncertain. In the case of results of magnetic declination, however, the Sun or star that serves for the magnetic observations usually permits of at least a fairly good determination of position.

REDUCTION FORMULÆ AND DETERMINATION OF CONSTANTS.

REDUCTIONS TO STANDARD INSTRUMENTS.

The extensive intercomparisons of magnetic instruments at Washington, in the field, and at magnetic observatories in all parts of the Earth, carried out by the Department of Terrestrial Magnetism, have made it possible to refer all its data to international magnetic standards within an error, in general, on the order of the observational error (see Volume II, pp. 211–278). Since the adopted constants for the sea instruments, as explained in the subsequent paragraphs, were made to depend upon the standardization data at shore stations (see pp. 296–309), the results derived from the magnetic observations on board the *Carnegie* are on the basis of the adopted magnetic standards.

MAGNETIC STANDARDS ADOPTED.

The magnetic standards adopted for reduction to a common basis of the results contained in the present volume are the so-called "C. I. W. Standards," as defined in Volume I (p. 42) and II (p. 16). These "C. I. W. Standards" are: In declination, C. I. W. magnetometer 3 without correction; in horizontal intensity, C. I. W. magnetometer 3 with a correction of $+0.00015H$ applied to observed values of the horizontal intensity, H, computed by the constants given for magnetometer 3 in Table 62, page 253; in inclination, earth inductor 48 with a correction of $-0'.5$ applied to observed values of inclination. A detailed discussion of the relations between the "C. I. W. Standards" and possible "International Magnetic Standards" is given in Volume II (pp. 270–278). It is shown there that the corrections of the originally selected standards are so small as to be negligible here. Accordingly, *the values of the magnetic elements, given in the Tables of Results on pages 261–309, may be regarded as based on "International Magnetic Standards."*

CONSTANTS AND CORRECTIONS FOR SEA INSTRUMENTS.

The instrumental constants and corrections on standards (above) of the sea instruments used in the *Carnegie* work were determined at Washington and at the various ports visited by comparisons with standardized land-instruments. The method adopted in the comparisons was generally that of simultaneous observations. In order to refer values of the magnetic elements at one observing station to any of the others, station differences were carefully determined at each port from observations with the land instruments, following the methods described in Volume I (pp. 19, 20).

DECLINATION OBSERVATIONS.

Marine collimating-compass.—The marine collimating-compass, designed and constructed by the Department of Terrestrial Magnetism, has been used as the standard declination-instrument for the *Carnegie* work. Description of the compass, its theory, and explanation of its use, will be found on pages 177–190. Specimen observations and computations for a sea station are given on pages 213–215. The introduction of the collimating principle has facilitated the control of instrumental constants, so that in the field only two have to be determined for each scale, viz, (1) the magnetic-axis and index error, A_c, and (2) the elevation, m. The constants can be determined at shore stations with an accuracy much greater than that for declination determinations at sea, and are, further-

more, susceptible of accurate adjustment by the method of least squares (see pp. 185–189). For specimen determinations of constants, see page 186.

Revolving-compass pattern of sea deflector.—The improved sea-deflector, designed and constructed by the Department of Terrestrial Magnetism, has been used as an auxiliary declination-instrument on board the *Carnegie*. For descriptions of the various forms of the instrument and explanation of its use, see pages 190–195. Specimen observations and computations for a sea station are given on pages 215–218. The purely instrumental corrections arise from (1) card-graduation errors and eccentricity of card mounting; (2) magnetic-axis and index error; (3) lack of correct adjustment of the sighting vanes attached to the bowl. Card-graduation errors, ϵ, were determined at shore stations by observing the magnetic azimuths of series of marks in the horizon, *i. e.*, at an altitude practically 0°, the marks being selected to give as nearly equal angular distribution as possible. The magnetic azimuths were controlled by simultaneous declination observations with a standardized magnetometer at a second station. For deflector 3 the card-graduation and eccentricity errors are small (see p. 235), while for deflector 4 they are entirely negligible. The corrections, A_{bc} for the "bright-line" method and A_{sc} for the "shadow" method, both include corrections for the second and third classes of errors above; they may vary with the altitude of the object sighted upon. The data for the establishment, by graphical means, of a curve representing the variation with change in altitude, were secured at shore stations from series of declination observations on the Sun. The absolute values of the declination were determined from simultaneous observations with the standardized magnetometer. The total correction to the card reading, depending upon the sighting method used, is $\epsilon+A_{bc}$ or $\epsilon+A_{sc}$.

Each of the terms making up the total correction to the observed card reading, viz, ϵ, and A_{bc} or A_{sc}, is given separately in this volume for each deflector. The signs attached are in the sense of continuous graduation from the south point as 0° through 360° in a clockwise direction. Accordingly, all card-readings in the southwest and northeast quadrants, that is, all readings from S to S 90° W (or W) and from N to N 90° E (or E), must be numerically increased when the sign given for ϵ, A_{bc}, or A_{sc} is plus (+) and *vice versa;* all card-readings in the other two quadrants must be numerically decreased when the sign given for ϵ, A_{bc}, or A_{sc} is plus (+), and *vice versa*.

Specimen observations and computations to determine the change in A_{bc} with altitude are given on page 234.

Marine collimating-compass 1 (C1).—Marine collimating-compass 1, designed and constructed by the Department of Terrestrial Magnetism, was used on the *Carnegie* from September 1909 to October 1916. During April to May 1914, before Cruise III, the instrument was thoroughly overhauled and repaired.

The adopted constants, resulting from least-square adjustments of all available data, are given in Table 52. Specimen observations for the determination of constants are given on page 186.

Sea deflector 3 (D3).—The adopted periodic corrections to observed card-readings of the compass of D3, used on Cruises I and II (as far as Cape Town, March 1911), are given in Table 53.

The adopted correction, A_{sc}, to observed card-readings by the "shadow" method is for all altitudes:

$$A_{sc} = +0^{\circ}.09 \text{ from August 1909 to September 1910}$$
$$A_{sc} = -0.06 \text{ from October 1910 to March 1911}$$

The adopted corrections, A_{bc}, to observed card-readings by the "bright-line" method, deduced from a graphical adjustment of all available data, vary with the Sun's altitude, and are given in Table 54.

Specimen Declination Observations with Sea Deflector at Shore Station

Station: *A*, Suva Vou, Fiji — *Date:* Wed., June 12, 1912, P. M. — *Obs'r:* H. F. J.
Instrument: Sea Deflector 4 — *Chron'r:* No. 13733

Method: Bright Line

No. of Reading	Set I Chron'r Time	Set I Card Reading	Set II Chron'r Time	Set II Card Reading
	h m s	°	h m s	°
1	4 08 00	292.75	4 18 00	291.50
2	08 30	2.75	18 30	1.55
3	09 00	2.75	19 00	1.50
4	09 30	2.70	19 30	1.50
5	10 00	2.70	20 00	1.45
6	13 00	2.30	23 00	1.00
7	13 30	2.10	23 30	1.00
8	14 00	2.05	24 00	0.95
9	14 30	2.05	24 30	0.95
10	15 00	2.00	25 00	0.90
Means	4 11 30	292.42	4 21 30	291.23

No.	Set III Chron'r Time	Set III Card Reading	Set IV Chron'r Time	Set IV Card Reading
1	4 26 00	290.70	4 32 00	290.05
2	26 30	0.75	32 30	0.00
3	27 00	0.70	33 00	290.00
4	27 30	0.70	33 30	289.95
5	28 00	0.60	34 00	9.90
6	29 00	0.30	35 00	9.85
7	29 30	0.25	35 30	9.80
8	30 00	0.15	36 00	9.80
9	30 30	0.15	36 30	9.75
10	31 00	0.10	37 00	9.70
Means	4 28 30	290.44	4 34 30	289.88

Remarks

Magnetic articles removed: Yes

Chronometer Comparisons

	Before	After
	h m s	h m s
Stan. Chron.	20 19 03	6 30 15
Stan. Chron. Corr.	−2 52	−2 52
G. M. T.	20 16 11	6 27 23
Equation of Time	+0 29	+0 29
G. A. T.	20 16 40	6 27 52
Longitude	11 53 40	11 53 40
L. A. T.	8 10 20	18 21 32
Chron. 13733	20 21 20	6 32 29
13733 on L. A. T.	−12 11 00	−12 10 57
Mean Corr. 13733 on L. A. T.		−12 10 58

Sun's Declination: 23°.14 N

Specimen Determinations of Declination Constant of Sea Deflector

Station: *A*, Suva Vou, Fiji — *Lat.:* 18° 07′.1 S — *Long.:* 178° 25′.1 E
Date: Wed., June 12, 1912, P. M. — *Sun's Decl'n:* 23°.14 N — *Obs'rs:* H. F. J., and H. M. E.
Instrument: Sea Deflector 4

Set No.	Chronometer Time	Local Apparent Time	Card Reading S to W	Sun's Azimuth[1]	Resulting Declination	Standard *D* by Mag'r 2[2]	Resulting Value A_{sc}	Sun's Altitude[3]
	h m s	h m s	°	°	°	°	°	°
I	4 11 30	16 00 32	112.42	122.90	+10.48	+10.42	+0.06	18.3
II	4 21 30	16 10 32	111.23	121.73	+10.50	+10.42	+0.08	16.3
III	4 28 30	16 17 32	110.44	120.95	+10.51	+10.42	+0.09	14.9
IV	4 34 30	16 23 32	109.88	120.30	+10.42	+10.42	0.00	13.6
V	4 42 30	16 31 32	109.00	119.47	+10.47	+10.42	+0.05	12.0
VI	4 48 30	16 37 32	108.46	118.86	+10.40	+10.41	−0.01	10.8
VII	4 54 30	16 43 32	107.90	118.27	+10.37	+10.41	−0.04	9.5
VIII	5 02 30	16 51 32	107.04	117.50	+10.46	+10.41	+0.05	7.9
IX	5 08 30	16 57 32	106.54	116.96	+10.42	+10.41	+0.01	6.6
X	5 14 30	17 03 32	106.02	116.43	+10.41	+10.41	0.00	5.4

[1]Interpolated for the respective local apparent times from standard tables of Sun's true bearing.
[2]Simultaneous determinations of magnetic declination were made by Observer H. M. Edmonds at station *B*. They were referred to station *A* by means of the station-difference ($A - B$) = − 1′.6, and then reduced to C. I. W. Standard (C. I. W. − magnetometer 2 = + 0′.1).
[3]Interpolated for the respective local apparent times from standard tables of Sun's altitudes.

TABLE 52.—*Constants of Marine Collimating-Compass C1.*

For Cruise	Scale	Magnetic Azimuth[1]		Scale Elevation[2]		Scale Value
		Designation	Value	Designation	Value[3]	
			°		° °	°
I and II	South	A_{cs}	0.37	m_s	−0.75 +1.27Z	0.98
	West	A_{cw}	90.71	m_w	+0.50	1.01
	North	A_{cn}	180.31	m_n	+0.93 −1.27Z	0.99
	East	A_{ce}	270.52	m_e	−0.10	1.02
III	South	A_{cs}	359.80	m_s	+0.02 +1.27Z	0.98
	West	A_{cw}	89.68	m_w	+0.16	1.01
	North	A_{cn}	179.87	m_n	+0.17 −1.27Z	0.99
	East	A_{ce}	269.94	m_e	−0.11	1.02

[1]The magnetic azimuths are on the basis of C. I. W. Standard and are reckoned continuously in a clockwise direction from the magnetic south as 0° through 360°.
[2]Elevations above the horizon are reckoned as positive, and below the horizon as negative.
[3]The vertical intensity, Z, is expressed in C. G. S. units, and is reckoned as positive for the northern magnetic hemisphere and negative for the southern magnetic hemisphere.

TABLE 53.—*Periodic Corrections to Card Readings of Compass D3.*

Card Reading	ε	Card Reading	ε	Card Reading	ε	Card Reading	ε
	°		°		°		°
South	+0.06	West	−0.11	North	+0.08	East	0.00
S 10° W	+0.04	N 80° W	−0.12	N 10° E	+0.09	S 80° E	0.00
S 20° W	+0.02	N 70° W	−0.13	N 20° E	+0.08	S 70° E	0.00
S 30° W	0.00	N 60° W	−0.13	N 30° E	+0.07	S 60° E	+0.01
S 40° W	−0.02	N 50° W	−0.11	N 40° E	+0.05	S 50° E	+0.02
S 50° W	−0.04	N 40° W	−0.08	N 50° E	+0.03	S 40° E	+0.03
S 60° W	−0.05	N 30° W	−0.04	N 60° E	+0.02	S 30° E	+0.05
S 70° W	−0.07	N 20° W	+0.01	N 70° E	+0.01	S 20° E	+0.07
S 80° W	−0.09	N 10° W	+0.05	N 80° E	0.00	S 10° E	+0.08

TABLE 54.—*Corrections to Observed Card-Readings of Compass D3 by the "Bright-Line" Method.*

For Cruise	Period	A_{bs} for Sun's Altitude					
		5°	10°	15°	20°	25°	30°
		°	°	°	°	°	°
I	Sept. 1909 to Feb. 1910....	+0.26	+0.26	+0.26	+0.24	+0.20	+0.15
II	June to Sept. 1910..........	+0.26	+0.26	+0.26	+0.24	+0.20	+0.15
	Oct. 1910 to March 1911....	+0.11	+0.11	+0.11	+0.09	+0.05	+0.00

The cause of the change in the index error, early in October 1910, at Pinheiro, is not known.

Sea deflector 4 (D4).—Sea deflector 4 was used on Cruise II, beginning at Cape Town in April 1911. The instrument was taken apart at Batavia, Java, in October 1911, to refasten one of the compass magnets which had become loose; it was again taken apart at Longwood, St. Helena, in June 1913, to remove an air bubble. The adjustments were altered somewhat at each reassembling of the instrument. There are no periodic corrections to observed card-readings of the compass D4. The "shadow" method was not used on Cruise II; however, it was used occasionally on Cruise III. The adopted corrections,

A_{bl} or A_{sl}, to observed card-readings by the "bright-line method," or by the "shadow method," deduced from graphical adjustments of all available data, are given in Table 55.

TABLE 55.—*Corrections to Observed Card-Readings of Compass D4.*

For Cruise	Period	A_{bl} for Sun's Altitude						
		0°	5°	10°	15°	20°	25°	30°
		°	°	°	°	°	°	°
II	April to Oct. 1911..........	+0.02	+0.02	+0.02	+0.02	+0.02	+0.02	+0.02
II	Nov. 1911 to Feb. 1912.....	+0.45	+0.47	+0.52	+0.59	+0.69	+0.81	+0.94
II	March 1912 to June 1913....	−0.07	+0.01	+0.09	+0.17	+0.25	+0.33	+0.41
II	July to Dec. 1913...........	+0.08	+0.08	+0.08	+0.08	+0.08	+0.08	+0.08
III	June to Oct. 1914..........	+0.03	+0.03	+0.03	+0.03	+0.03	+0.03	+0.03
		A_{sl} for Sun's Altitude						
		0°	5°	10°	15°	20°	25°	30°
		°	°	°	°	°	°	°
III	June to Oct. 1914..........	+0.46	+0.26	+0.18	+0.17	+0.19	+0.20	+0.21

HORIZONTAL-INTENSITY OBSERVATIONS WITH SEA DEFLECTOR.

As stated on page 191 and shown on the specimen form, page 217, the horizontal intensity is computed from sea-deflector observations by the formula

$$H = \frac{mC}{\sin u}$$

in which m is the magnetic moment of the deflecting magnet, C is a constant involving the deflection distance r, the distribution coefficients P and Q, the induction factor $\mu = mh$ (h being the induction coefficient for the deflecting magnet), and u the observed angular deflection produced by the deflecting magnet when its axis is perpendicular to that of the compass. The sea deflector is a relative instrument, and values of the so-called constant, $mC = H \sin u$, must be determined from comparison horizontal-intensity observations, made at shore stations with standardized absolute instruments.

The constant, mC, is subject to changes arising from (1) decrease in m with time, (2) effects of temperature variations on m and r, and (3) effects of change in vertical intensity, Z. In the *Carnegie* work all available data for log mC, except as noted below under the constants for deflector 3, were subject to least-square adjustment based on the general form

$$\log mC = \log mC_{20} \text{ at } \tau_0 + x\Delta\tau + y\,(z - Z)^2 + q\,(20° - t)$$

in which τ is the date of observation expressed in years, τ_0 is the selected reference date $\Delta\tau$ is $(\tau - \tau_0)$, q is the factor representing the combined effect of a change in temperature of 1° centigrade on m and C (on the latter because of the change in r), and t is the temperature of observation; the standard temperature of reference is 20° centigrade. Instead of deriving all the unknowns simultaneously it is found better to make a separate determination of the temperature factor, q, selecting the observations best suited for that purpose. The final results were arrived at by a process of successive approximations, in the last steps of which q was treated as a constant. Specimen determinations of mC at a shore station, and a table showing the observed and adjusted values of that constant for deflector 4 on Cruise II, are given on pages 240 and 241.

Sea deflector 3 (*DS*).—Sea deflector 3 of the revolving-compass pattern, designed and constructed by the Department of Terrestrial Magnetism, is described on pages 191 and 192 and illustrated on Plate 12, Figure 1. It was used on Cruises I and II (as far as Cape Town, March 1911). Since the courses followed during this period were such that the vertical intensity practically varied uniformly with the time, between successive shore determinations of mC, a graphical adjustment of the available data, referred to the standard temperature, 20° centigrade, was found to give, with sufficient accuracy, the value of this constant for each magnet and distance at any time. The temperature factors were determined as explained above. An examination of the data indicated that there were no periodic corrections to log mC, as was the case for the less-accurately made deflectors 1 and 2 used in the magnetic work on the *Galilee*.

The constants adopted on the basis of C. I. W. Standard (see p. 232) are given by the following equations, which are to be used in connection with the values of log mC at 20° centigrade, adopted from the graphical adjustments, and given in Table 56 for different dates:

$$\text{Magnet 45} \quad \log mC = \log mC \text{ at } 20^\circ \text{ for } \tau + 0.00026\,(20^\circ - t)$$
$$\text{Magnet 2L} \quad \log mC = \log mC \text{ at } 20^\circ \text{ for } \tau + 0.00014\,(20^\circ - t)$$

TABLE 56.—*Logarithms of Intensity Constants at 20° Centigrade of Sea Deflector 3 (Cruises I and II to March 1911)*

Date τ	Magnet 45 Distance[1] 1	Magnet 45 Distance[1] 3	Magnet 2L Distance[1] 1	Magnet 2L Distance[1] 3	Date τ	Magnet 45 Distance[1] 1	Magnet 45 Distance[1] 3	Magnet 2L Distance[1] 1	Magnet 2L Distance[1] 3
1909.55	9.0728	8.9440	9.0052	8.8734	1910.45	9.0737	8.9435	9.0036	8.8728
1909.60	9.0741	8.9443	9.0053	8.8734	1910.50	9.0730	8.9436	9.0032	8.8728
1909.65	9.0743	8.9444	9.0053	8.8735	1910.55	9.0732	8.9436	9.0030	8.8724
1909.70	9.0745	8.9445	9.0051	8.8735	1910.60	9.0733	8.9436	9.0028	8.8724
1909.75	9.0743	8.9430	9.0046	8.8730	1910.65	9.0733	8.9436	9.0024	8.8722
1909.80	9.0733	8.9427	9.0040	8.8730	1910.70	9.0730	8.9436	9.0023	8.8720
1909.85	9.0736	8.9430	9.0035	8.8730	1910.75	9.0731	8.9436	9.0023	8.8721
1909.90	9.0721	8.9417	9.0030	8.8737	1910.80	9.0735	8.9439	9.0022	8.8719
1909.95	9.0722	8.9417	9.0030	8.8737	1910.85	9.0730	8.9433	9.0021	8.8718
1910.00	9.0728	8.9419	9.0037	8.8730	1910.90	9.0743	8.9437	9.0019	8.8714
1910.05	9.0724	8.9430	9.0034	8.8733	1910.95	9.0746	8.9440	9.0018	8.8712
1910.10	9.0723	8.9427	9.0038	8.8737	1911.00	9.0746	8.9441	9.0018	8.8711
1910.15	9.0731	8.9433	9.0041	8.8741	1911.05	9.0746	8.9439	9.0020	8.8712
1910.20	9.0730	8.9434	9.0043	8.8743	1911.10	9.0746	8.9440	9.0022	8.8714
1910.25	9.0730	8.9435	9.0044	8.8746	1911.15	9.0751	8.9444	9.0022	8.8715
1910.30	9.0727	8.9436	9.0043	8.8743	1911.20	9.0755	8.9446	9.0021	8.8716
1910.35	9.0723	8.9435	9.0041	8.8736	1911.25	9.0757	8.9450	9.0020	8.8717
1910.40	9.0726	8.9435	9.0039	8.8733					

[1]The deflection distances 1 and 3 only were used for observations at sea.

Sea deflector 4.—Sea deflector 4 of the revolving-compass pattern, with numerous improvements on deflector 3 in mechanical detail, designed and constructed by the Department of Terrestrial Magnetism, is described on pages 192 and 193 and illustrated by Figures 2-6, Plate 12. It was used on Cruises II (from April 1911), III, and IV. during April and May 1914, preceding Cruise III, it was thoroughly overhauled and repaired. A slight leak developed in the inner lining of the bowl during Cruise II, and again during Cruise IV, but did not affect the intensity constants. It appears that some change, of unknown cause, took place in magnet 45 just before the comparison observations at Antipolo in February 1912; that the change occurred at Antipolo is borne out by comparisons of the sea values of H before and after this station, obtained separately from observations with the two magnets 45 and 2L.

The adopted constants for Cruise II from April 1911, on the basis of C. I. W. Standard (see p. 232), resulting from least-square adjustments of all the available data, are given in

Table 57. An examination of the data showed that there were no periodic corrections to log mC, as was the case for the deflectors 1 and 2, used in the *Galilee* work. In the table, $\Delta\tau = (\tau - 1911.24)$.

TABLE 57.—*Intensity Constants of Sea Deflector 4, for Cruise II.*

Period	Deflecting Magnet[1]	Deflection Distance[2]	Logarithms of the Intensity Constant
Mar. 1911 to Feb. 1912...	45	1	$mC = 9.05805 + 0.00100\Delta\tau + 0.03330(-0.140 - Z)^2 + 0.00026(20^\circ - t)$
	45	3	$mC = 8.93120 + 0.00158\Delta\tau + 0.05110(-0.140 - Z)^2 + 0.00026(20 - t)$
Mar. 1912 to Dec. 1913...	45	1	$mC = 9.05546 + 0.00012\Delta\tau + 0.00257(+0.322 - Z)^2 + 0.00026(20 - t)$
	45	3	$mC = 8.92947 - 0.00003\Delta\tau + 0.00340(+0.174 - Z)^2 + 0.00026(20 - t)$
Mar. 1911 to Dec. 1913...	2L	1	$mC = 8.98478 - 0.00115\Delta\tau + 0.00837(+0.072 - Z)^2 + 0.00014(20 - t)$
	2L	3	$mC = 8.85821 - 0.00108\Delta\tau + 0.00797(+0.076 - Z)^2 + 0.00014(20 - t)$

[1]Magnet 3 was not used at sea. [2]Deflection distances 1 and 3 only were used at sea.

The constants adopted on the basis of C. I. W. standard (see p. 232) for sea deflector 4 during Cruise III are given by the following equations:

Magnet 45 $\log mC = \log mC$ at 20° for $\tau + 0.00026\ (20^\circ - t)$
Magnet 2L $\log mC = \log mC$ at 20° for $\tau + 0.00014\ (20^\circ - t)$
Magnet 3 $\log mC = \log mC$ at 20° for $\tau + 0.00025\ (20^\circ - t)$

The values of log mC at 20° centigrade and for the time τ, are taken from Table 58, which was constructed from the time graphs actually used in the final reduction of the observations. The range in the values of Z for this cruise was very small, and there was no indication that the results would be improved by such an adjustment as was made for Cruise II.

TABLE 58.—*Logarithms of the Intensity Constants at 20° Centigrade of Sea Deflector 4, for Cruise III.*

Date τ	Magnet 45 Distance				Magnet 2L Distance				Magnet 3 Distance				Shore Station
	1	2	3	4	1	2	3	4	1	2	3	4	
1914.38	9.0560	8.9912	8.9297	8.8759	8.9821	8.9174	8.8559	8.8020	8.7080	8.6445	8.5810	8.5286	Washington
.40	61	13	296	59	22	75	60	21	80	46	12	86	
.45	65	14	294	59	23	77	62	23	81	47	18	86	
.50	69	16	292	59	24	80	63	26	82	49	24	85	
.54	71	17	290	59	25	82	65	28	83	50	28	85	Hammerfest
.55	72	17	291	59	26	83	66	29	84	50	28	85	
.60	73	17	295	61	30	86	70	32	88	51	29	88	
.65	74	17	299	62	35	90	74	35	93	51	30	90	
.67	74	17	301	63	36	91	75	36	94	52	30	91	Reykjavik
.70	73	16	301	63	36	92	75	37	95	53	28	91	
.75	70	15	300	65	35	92	73	39	96	55	24	90	
.80	65	13	300	66	34	92	72	41	97	58	21	89	
.85	58	11	300	68	33	93	71	43	98	60	17	88	
.86	56	11	300	68	32	93	71	43	98	61	16	88	Washington

Discussion of changes in intensity constants of sea deflector.—As already stated (see p. 236), the intensity constant, $mC = H \sin u$, is subject to change[1] because of (1) the effect of change in the temperature, t, both on the magnetic moment, m, and on the deflection distance, r; (2) the effect arising from the aging of the deflecting magnet and the consequent time-change in m; and (3) the effect due to change in the vertical intensity, Z.

[1]It is assumed that possible changes in the distribution coefficients, P and Q, for the deflecting and compass magnets, and in the induction factor μ ($\mu = mh$, where h is the induction coefficient for the deflecting magnet), are so small as to be negligible for work at sea.

The first effect (1) may be expressed by the introduction of a temperature factor q in a term of the form $q\Delta t$. The factor q may be determined from shore observations by selecting those best suited, *i. e.*, those made at stations where the range in temperature during observations has been large, and for which magnetic conditions were normal. The separate determinations of q from various shore observations must be weighted according to the mean range of temperature from which each is deduced; it may also be necessary to weight values somewhat according to the magnetic conditions at the station concerned. Every precaution must be taken, of course, to guard against sudden or irregular temperature changes during observations to determine constants at shore stations.

The second effect (2) may be expressed satisfactorily, at least for well-seasoned magnets, by a term involving the first power of the difference in time from some selected epoch, τ_0, and an aging coefficient x, thus: $x\,(\tau - \tau_0)$, or $x\Delta\tau$.

The third effect (3) is more complex. There is a value of the vertical intensity, designated z, for which the magnetic field of the compass system of magnets, tilted about the pivot support by the action of Z, is symmetrically disposed with reference to the field of the deflecting magnet. Any departure of the magnet system from this balanced position, such as occurs when the instrument is at a station for which the value of Z is different from z, always increases the constant mC. This is shown by examination of the deflector intensity-constants on Cruises I to IV, for each magnet and for each distance used. The third effect (3) may, accordingly, be expressed by a squared term, involving the unknown z, as defined above, and multiplied by a vertical-intensity factor y, thus: $y\,(z-Z)^2$.

It appears, therefore, that the variable intensity-constants for the deflector may be expressed by the general formula

$$\log mC = w + x\Delta\tau + y\,(z - Z)^2 + q\Delta t$$

in which w represents the value of log mC at a standard temperature, t_s, for an epoch, τ_0, at a place where the vertical intensity is z; and in which Δt is $(t_s - t)$, t being the temperature of observation.

To obtain data for the determination of the intensity constants and their changes, observations of intensity with the sea deflector are made at every port for each deflecting magnet and each deflection distance. Simultaneous determinations of intensity are always obtained with a standardized magnetometer at an auxiliary station; the correction for the difference in intensity between the two stations is determined by simultaneous magnetometer observations, involving exchange of station in accordance with the usual practice (see Vol. I, p. 219). The deflector observations are always made for four different orientations of the bearing ring, to eliminate and determine possible periodic effects. The scheme of observation followed is similar to that used on board ship (see p. 194).

On page 240 are given specimen horizontal-intensity observations with sea deflector 4 at the shore station Suva Vou, A, Fiji, for the deflecting magnet 45 at deflection distances 1 and 3 and for the orientation 0°, together with an abstract of all the results and computations of log mC_t at the same station, for both deflecting magnets 45 and 2L at deflection distances 1 and 3. Observations to determine log mC for magnet 2L at distances 1 and 3 for orientation 0°, corresponding to those given in the specimen for magnet 45, were made between chronometer times $3^h\ 22^m$ and $4^h\ 02^m$ and $3^h\ 31^m$ and $3^h\ 53^m$, respectively; those determinations thus apply to practically the same mean time as the determinations with magnet 45. The same order of observation is followed for each orientation.

Specimen Horizontal-Intensity Observations with Sea Deflector at Shore Station

Station: A, Suva Vou, Fiji *Date:* Tues., June 11, 1912 *Obs'r:* H. F. J.
Instrument: Deflector No. 4 *Mark:* Flagstaff on lower lighthouse *Chron'r:* 13733

Orientation	0°				0°			
Magnet; Set	Magnet 45; Set I				Magnet 45; Set II			
Distance	U1	L1	L1	U1	U3	L3	L3	U3
North End of Magnet	E	E	W	W	W	W	E	E
Sight Line	*L*2 to 180°		*L*2 to 0°		*L*2 to 0°		*L*2 to 180°	
Vernier *A* reads	124°.21	125°.50	265°.87	267°.02	271°.72	271°.11	120°.30	119°.50
Sight Line	*L*2 to 0°		*L*2 to 180°		*L*2 to 180°		*L*2 to 0°	
Vernier *B* reads	124°.10	125°.21	265°.92	267°.12	271°.82	271°.11	120°.28	119°.32
Mean Vernier Reading	124.16	125.36	265.90	267.07	271.77	271.11	120.29	119.41
Mean Reading (U and L)	124.76		86.48		91.44		119.85	
Mean 2*u*	38.28				28.41			
Mean *u*	19.14				14.20			
Magnetic meridian	105.62				105.64			
	h m				*h m*			
Chronometer time	2 50				4 34			
Mark reads on card	299°.85				299°.90			
Mark reads on circle	345.95	Vernier *A*			165.88	Vernier *B*		

Remarks

Corr'n of Chron'r 13733 on L. M. T. is $-12^h\ 11^m$
Magnetic articles were removed from observer and tent before beginning observations

	Set I Time	Set I Temp.	Set II Time	Set II Temp.
	h m	°*C*	*h m*	°*C*
Beginning	2 52	24.1	3 07	23.0
Ending	4 22	22.7	4 11	22.8
Means	3 37	23.4	3 39	22.9
Corr'n 13733	−12 11		−12 11	
L. M. T.	15 26		15 28	

Specimen Determinations of Intensity Constant of Sea-Deflector

Station: A, Suva Vou, Fiji *Date:* June 11, 12, 1912 *Obs'r:* H. F. J.
Instrument: Deflector No. 4

Date	Orientation	Local Mean Time	Observed Deflection-Angle, *u*: Magnet 45, Distance 1, *t*	Magnet 45, Distance 1, *u*	Magnet 45, Distance 3, *t*	Magnet 45, Distance 3, *u*	Magnet 2L, Distance 1, *t*	Magnet 2L, Distance 1, *u*	Magnet 2L, Distance 3, *t*	Magnet 2L, Distance 3, *u*	Horizontal Intensity[1] C. I. W. Standard
1912	°	*h*	°*C*	°	°*C*	°	°*C*	°	°*C*	°	*c. g. s.*
June 11	0	15.4	23.4	19.14	22.9	14.20	22.9	16.14	22.9	12.03	0.34703
12	90	11.4	24.8	19.08	24.7	14.16	24.4	16.07	24.6	11.89	.34741
12	180	13.6	25.4	19.08	25.6	14.17	26.0	16.11	25.6	11.96	.34711
12	270	15.0	26.9	19.08	26.6	14.13	26.8	16.09	26.4	11.98	.34720
Means			25.12	19.095	24.95	14.165	25.02	16.102	24.88	11.965	0.34719
Log sin *u*			9.51473		9.38866		9.44302		9.31663		
Log *H*			9.54057		9.54057		9.54057		9.54057		
Log mC_t			9.05530		8.92923		8.98359		8.85720		
Log *mC* at mean observed *t*, 25°.0[2]			9.05533		8.92922		8.98359		8.85718		

[1]The simultaneous horizontal-intensity observations with magnetometer 2, reduced to C. I. W. Standard, were made at station Suva Vou, *B*, and were referred to station Suva Vou, *A*, by means of the station-difference (*A* − *B*) = +0.00051 C. G. S. unit, determined from magnetometer comparisons.
[2]Using the temperature-factor values 0.00026 and 0.00014: or magnets 45 and 2L, respectively.

Table 59 gives a condensed summary of the observed and computed data for the adopted intensity-constants of sea deflector 4, used on Cruise II during April 1911 to December 1913. This table is typical of the reductions made for each deflecting needle and each deflection distance for the separate cruises.

TABLE 59.—*Intensity Constants of Sea Deflector 4, Determined at Shore Stations during Cruise II.*

Station	Date	Magnetic Elements			Logarithms of Intensity Constant mC[1] — Observed Values at Temperature, t					
					Magnet 45			Magnet 2L		
		H	I	Z	t	Distance 1	Distance 3	t	Distance 1	Distance 3
		c. g. s.	°	c. g. s.	°C			°C		
Cape Town, *D*	1911.24	0.176	−60.0	−0.304	21.2	9.05864	8.93230	22.4	8.98572	8.85949
Colombo, *B*	1911.45	0.382	− 4.6	−0.031	30.4	9.05596	8.92938	30.5	8.98382	8.85671
Mauritius[*3]	1911.60	0.233	−54.5	−0.322	24.5	9.05835	8.93225	24.5	8.98494	8.85813
Colombo, *A* and *B*	1911.70	0.381	− 4.6	−0.030	30.3	9.05622	8.92993	30.3	8.98263	8.85659
Batavia[4]	1911.84	0.367	−31.3	−0.224	29.2	9.05648	8.93012	29.1	8.98320	8.85664
Antipolo, *B* and *C*[5]	1912.11	0.382	+16.2	+0.111	29.9	9.05291	8.92653	29.9	8.98229	8.85575
Suva Vou, *A*	1912.44	0.347	−38.5	−0.278	25.0	9.05533	8.92922	25.0	8.98359	8.85718
Papeete[*6]	1912.72	0.339	−29.6	−0.193	26.5	9.05464	8.92828	26.5	8.98221	8.85590
Coronel, *A*	1912.91	0.267	−35.5	−0.190	18.5	9.05681	8.93051	18.4	8.98404	8.85689
Port Stanley, *B* and *C*	1913.12	0.265	−45.9	−0.273	13.1	9.05837	8.93165	13.2	8.98505	8.85867
Jaburu, *B* and *C*	1913.33	0.265	− 2.4	−0.011	27.6	9.05414	8.92780	27.8	8.98116	8.85489
Longwood,[*] *B* and *C*	1913.49	0.218	−37.2	−0.166	19.0	9.05628	8.92974	18.9	8.98283	8.85652
Falmouth, *B*	1913.71	0.188	+66.5	+0.432	16.7	9.05695	8.93082	17.0	8.98351	8.85719
Washington, *C*	1914.04	0.192	+70.9	+0.555	9.0	9.05858	8.93240	9.1	8.98499	8.85835

Station	Date	Logarithms of Intensity Constant mC[1] — Computed Values[2] at Temperature t				Logarithm Differences (Observed Minus Computed)			
		Magnet 45 Distance		Magnet 2L Distance		Magnet 45 Distance		Magnet 2L Distance	
		1	3	1	3	1	3	1	3
Cape Town, *D*	1911.24	9.05864	8.93226	8.98562	8.85902	.00000	+.00004	+.00010	+.00047
Colombo, *B*	1911.45	9.05596	8.92944	8.98316	8.85660	.00000	−.00006	+.00066	+.00011
Mauritius[*3]	1911.60	9.05834	8.93229	8.98504	8.85845	+.00001	−.00004	−.00010	−.00032
Colombo, *A* and *B*	1911.70	9.05623	8.92987	8.98289	8.85636	−.00001	+.00006	−.00026	+.00023
Batavia[4]	1911.84	9.05650	8.93012	8.98356	8.85701	−.00002	.00000	−.00036	−.00037
Antipolo, *B* and *C*[5]	1912.11	9.05311	8.92688	8.98240	8.85589	−.00020	−.00035	−.00011	−.00014
Suva Vou, *A*	1912.44	9.05522	8.92882	8.98373	8.85721	+.00011	+.00040	−.00014	−.00003
Papeete[*6]	1912.72	9.05462	8.92820	8.98276	8.85628	+.00002	+.00008	−.00055	−.00038
Coronel, *A*	1912.91	9.05671	8.93026	8.98366	8.85719	+.00010	+.00025	+.00038	−.00030
Port Stanley, *B* and *C*	1913.12	9.05838	8.93188	8.98457	8.85810	−.00001	−.00023	+.00048	+.00057
Jaburu, *B* and *C*	1913.33	9.05400	8.92755	8.98135	8.85492	+.00014	+.00025	−.00019	−.00003
Longwood,[*] *B* and *C*	1913.49	9.05659	8.93005	8.98281	8.85640	−.00031	−.00031	+.00002	+.00012
Falmouth	1913.71	9.05664	8.93049	8.98345	8.85697	+.00031	+.00033	+.00006	+.00022
Washington, *C*	1914.04	9.05878	8.93274	8.98504	8.85855	−.00020	−.00034	−.00005	−.00020

[*]Stations so marked are locally disturbed.
[1]All values are based on C. I. W. Standards.
[2]For the formulæ adopted from least-square adjustments, see Table 57, p. 238.
[3]The observations were made at Pamplemousses, stations *B* and *C*.
[4]The observations were made at Weltevreden, stations *A* and *B*.
[5]There was a change in the condition of magnet 45 just before the shore observations at Antipolo and therefore a change in the adopted formulæ for this magnet from Antipolo. (See p. 238.)
[6]The observations were made at stations *A* and *B* on small coral island in Papeete Harbor.

INCLINATION OBSERVATIONS.

Sea dip-circle.—Specimen observations and computations for the determination of inclination, I, on board ship with the sea dip-circle, are fully shown on pages 219–222. Inclination corrections for each needle were determined at Washington, and at each shore station, by comparisons between the sea dip-circles and standardized land dip-circles or standardized earth-inductors. During the *Carnegie* cruises inclinations were almost always observed with both polarities of the regular dip-needles. When that was not done, polarity corrections were derived from preceding and following observations, made with both polarities.

The deterioration of the dip-needle pivots, used with the circles on the *Carnegie*, was more rapid than on the *Galilee*. It is probable that the greater trouble experienced on that account was caused chiefly by the gases and waste products unavoidably present in the engine and gas-producer rooms, which are quite close to the instrument store-room, supplemented by the large temperature changes during the operation of the gas-producer plant and gas engine. This rapid deterioration of pivots caused both progressive and erratic time-changes in the inclination corrections, in addition to those changes which depend upon magnetic field and upon pivot-section irregularities. It was thus not possible, in the *Carnegie* work, to rely wholly on least-square adjustments of the available data in accordance with the general formula

$$F\Delta I = x + z \cos I + y \sin I$$

which was used for practically all of the *Galilee* work. The adopted corrections, therefore, for Cruises I to IV, except for Cruise I, are based upon a combination of (1) adjusted formulæ corresponding to the above equation, and (2) a linear time-change between the corrections determined at successive shore stations.

Specimen observations and reductions for determination of inclination corrections are given on pages 243–246. These specimens are typical of the determinations made for each needle at a shore station. The order of observation followed is such that the mean times of the needles in a set of determinations will be practically the same. The order, for example, with a circle provided with dip needles 1 and 2, and intensity-needle pair 3 and 4, would be: (1) inclination observations with polarity A north for needle 1, (2) corresponding observations with needle 2, (3) loaded-dip observations with needle 4, (4) deflected-dip observations with suspended needle 3 "face direct" at short deflection-distance, (5) corresponding observations with needle 3 at long deflection-distance, (6) deflected-dip observations with suspended needle 3 "face reversed" at long deflection-distance, (7) corresponding observations with needle 3 at short deflection-distance, (8) loaded-dip observations with needle 4, (9) inclination observations with polarity B north with needle 2, and finally (10) corresponding observations with needle 1. For a typical compilation, showing the observed and adjusted values of inclination corrections for an entire cruise, see Table 19, page 72.

Marine earth-inductor.—The satisfactory performances of earth inductors of various makes and designs, as evidenced by the extensive comparison work of the Department of Terrestrial Magnetism, indicated that the inclination correction for a well-made inductor is practically the same for all magnetic fields. In view of the difficulties experienced, because of the changes with magnetic field in the needle inclination-corrections of the sea dip-circles, and particularly because of the more or less erratic changes arising from unavoidable needle-pivot deterioration, the desirability of adapting the earth inductor for use on board ship was early appreciated. Therefore, after an extended theoretical study of the conditions involved,[1] the design and construction of an earth inductor, with appurtenances suitable for observation at sea, was undertaken by the Department of

[1] *Cf.* Dorsey, N. E. The Theory of the Earth Inductor as an Inclinometer. *Terr. Mag.*, vol. 18, pp. 1–38.

Inclination Observations with Sea Dip-Circle at Shore Station

Station: A, Suva Vou, Fiji	*Date:* Mon., June 17, 1912	*Obs'r:* H. D. F.
Dip Circle: No. 189	*Needle:* No. 5	*Chron'r:* No. 51

End of needle marked *A* south down							Micro. *A*: Down
Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
141 45 44	321 52 52	38 18 21	218 26 28	38 06 06	218 02 00	141 27 25	321 27 25
38 15.5	38 08.0	38 19.5	38 27.0	38 06.0	38 01.0	38 34.0	38 34.0
−38° 11′.8		−38° 23′.2		−38° 03′.5		−38° 34′.0	
−38° 17′.5				−38° 18′.8			
Mean: −38° 18′.2							

Polarity[1] reversed			End of needle marked *B* south down				Micro. *A*: Up
Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
141 38 37	321 28 32	37 54 49	217 50 46	38 20 20	218 25 26	141 59 59	322 07 07
38 22.5	38 30.0	37 51.5	37 48.0	38 20.0	38 25.5	38 01.0	37 53.0
−38° 26′.2		−37° 49′.8		−38° 22′.8		−37° 57′.0	
−38° 08′.0				−38° 09′.9			
Mean: −38° 09′.0							

Resulting Inclination: −38° 13′.6 − 0′.0[2] = −38° 13′.6

	h m		° ′
Chron. time of beginning	12 37	Circle in mag. prime vertical	
Chron. time of ending	14 17	Circle N. Needle S. end	78 52
		Needle N. end	78 43
Mean chronometer time	13 27	Circle S. Needle N. end	259 00
Chron. correction on L. M. T.	0 00	Needle S. end	259 12
Local mean time	13 27	Mean	78 57
Magnetic meridian reads	168° 57′ 348 57	Remarks: Footscrew *C* was north	

[1]Polarity reversed by 10 strokes of bar magnets on each face.

[2]The so-called polarity-correction.

Specimen Determinations of Inclination Corrections of Sea Dip-Circle

Station: A and B, Suva Vou, Fiji *Date:* June 17, 18, 19, 1912 *Obs'rs:* H. D. F. and H. M. E.
Instrument: Sea dip-circle 189

Date	Local Mean Time		Inclination Obtained[1]					
			C. I. W. by E. I. 2[2]	Needle No.				
				5	9	6	7_{DRS}[3]	7_{DRL}[3]
1912	h	m	° ′	° ′	° ′	° ′	° ′	° ′
June 17	13	27	−38 28.9	−38 13.6	−38 33.2	....	....	....
17	13	30	29.0	....	....	....	−38 41.8	−38 19.6
17	15	04	28.8	11.8	33.0	....	40.2	18.7
18	10	55	27.9	13.6	33.0	....	42.0	19.1
18	12	06	28.1	....	....	....	....	19.6
18	14	55	28.9	....	32.7	−38 27.8	....	....
18	14	55	28.9	....	....	25.6	....	....
19	10	43	28.0	12.3	32.4	....	42.0	16.6
19	12	36	28.1	12.5	33.8	....	39.9	15.9
19	14	47	28.0	12.4	34.6	27.5	....	....
19	14	48	28.0	....	....	26.3	....	....
19	14	51	27.8	....	....	....	39.3	17.0

Date	Local Mean Time		Resulting Corrections Sea Dip-Circle 189 Needle No.					Remarks
			5	9	6	7_{DRS}[3]	7_{DRL}[3]	
1912	h	m	′	′	′	′	′	
June 17	13	27	−15.3	+4.3	....	....	....	Earth inductor 2 at *B*; dip circle 189 at *A*
17	13	30	....	....	....	+12.8	− 9.4	
17	15	04	−17.0	+4.2	....	+11.4	−10.1	
18	10	55	−14.3	+5.1	....	+14.1	− 8.8	
18	12	06	....	....	....	....	− 8.5	
18	14	55	....	+3.8	−1.1	....	....	
18	14	55	....	....	−3.3	....	....	
19	10	43	−15.7	+4.4	....	+14.0	−11.4	Earth inductor 2 at *A*; dip circle 189 at *B*
19	12	36	−15.6	+5.2	....	+11.8	−12.2	
19	14	47	−15.6	+6.6	−0.5	....	....	
19	14	48	....	....	−1.7	....	....	
19	14	51	....	....	....	+11.5	−10.8	
Mean inclination-corrections			−15.6	+4.8	−1.6	+12.6	−10.2	

[1] All values are referred to *A*; *A* = *B* − 0′.1.
[2] The correction applied to observed values by earth inductor 2, to reduce them to C. I. W. Standard, was −0′.7.
[3] 7_{DRS} is the designation for the mean value for needle 7 in direct and reversed positions when deflected by needle 8 at the short deflection-distance; 7_{DRL} is the corresponding designation for the long deflection-distance.

Terrestrial Magnetism. A description of the instrument and accessories, its theory, an explanation of its use, and specimen observations and computations for magnetic inclination on board ship, are given on pages 196–202 and 221–224.

At each shore station comparison observations are made between the marine earth-inductor and the standardized land earth-inductor, to control any possible change in the inclination correction of the first instrument, as well as its constancy. Specimen determinations at a shore station with the marine inductor, and a specimen summary of the results for an entire set at a single shore station, are given on pages 245–246.

Marine earth-inductor 3.—Marine earth-inductor 3 was used on the *Carnegie* during Cruises II (from September 1912), III, and IV. This instrument, with its special reversible gimbal-stand for use on board ship, was designed and constructed by the Department of Terrestrial Magnetism. It is provided with a marine moving-coil galvanometer, designed and constructed by the Leeds and Northrup Company. The adopted inclination-correction from all available data is, for all values of inclination, −1′.0.

Inclination Observations with Marine Earth-Inductor at Shore Station

Station: Jarrah Peg, Christchurch, N. Z. *Date:* Fri., Apr. 28, 1916 *Obs'r:* I. A. L.
Marine Earth Inductor: No. 3 *Footscrew:* *A* north *Chron'r:* No. 53151

Commutator Down					Commutator Up				
Circle East									
Chron. Time	Rotation[1]	Vertical Circle Ver. *A*	*B*	Mean	Chron. Time	Rotation	Vertical Circle Ver. *A*	*B*	Mean
h m		° ′	′	° ′	h m		° ′	′	° ′
16 09	+	68 06.5	06.2	68 06.4	16 42	+	248 04.5	03.5	248 04.0
	−	10.0	08.8	09.4		−	06.0	05.0	05.5
	−	09.5	09.0	09.2		−	06.4	05.5	06.0
16 16	+	07.4	06.6	07.0	16 48	+	05.0	04.0	04.5
16 12	Means			68 08.0	16 45	Means			248 05.0
Inclination for Circle East				−68 08.0	Inclination for Circle East				−68 05.0
Circle West									
16 20	+	111 51.5	51.0	111 51.2	16 33	+	291 52.0	51.5	291 51.8
	−	53.5	53.5	53.5		−	55.5	54.4	55.0
	−	53.2	52.8	53.0		−	55.6	54.4	55.0
16 26	+	50.5	50.0	50.2	16 39	+	54.5	53.5	54.0
16 23	Means			111 52.0	16 36	Means			291 54.0
Inclination for Circle West				−68 08.0	Inclination for Circle West				−68 06.0
Mean Inclination Commutator Down				−68 08.0	Mean Inclination Commutator Up				−68 05.5

	Commutator Down	Commutator Up
	h m	h m
Mean chron. time	16 17	16 40
Chron. corr. on L. M. T.	−0 49	−0 49
Local mean time	15 28	15 51

Magnetic Meridian Compass End	Horizontal Circle
	° ′
North	138 38
South	318 38
South	318 14
North	138 13
Mean	138 26

Remarks
Magnetic meridian reads 138° 26′ and 318° 26′ by Vernier *A*

[1]Plus stands for coil spun in right-hand direction, and minus for coil spun in left-hand direction.

Specimen Determinations of Inclination Corrections of Marine Earth-Inductor

Stations: Jarrah Peg and Brass Pipe, Christchurch, N. Z. | *Date:* April 28, 29, May 2, 1916 | *Instrument:* Marine earth-inductor 3 | *Obs'vs:* H. M. E. and I. A. L.

Date	Local Mean Time		Inclination Obtained[1] C. I. W. by Inductor 25[2]	Earth Inductor 3 Commutator Up	Earth Inductor 3 Commutator Down	Resulting Corrections Earth Inductor 3 Commutator Up	Resulting Corrections Earth Inductor 3 Commutator Down	Remarks
1916	*h*	*m*	° ′	° ′	° ′	′	′	
Apr. 28	14	42	−68 06.5	....	−68 05.6	....	−0.9	
28	15	06	06.5	....	06.2	....	−0.3	
28	15	28	07.6	....	08.0	....	+0.4	
28	15	51	05.9	−68 05.5	....	−0.4	....	
28	16	10	05.3	04.9	....	−0.4	....	
28	16	27	06.3	05.8	....	−0.5	....	Inductor 25 at station *Brass Pipe;* inductor 3 at station *Jarrah Peg*
29	9	26	05.4	....	05.6	....	+0.2	
29	9	53	05.6	....	06.0	....	+0.4	
29	10	10	05.6	05.2	....	−0.4	....	
29	10	28	06.1	05.8	....	−0.3	....	
29	10	56	08.3	....	08.2	....	−0.1	
29	11	13	10.3	....	10.2	....	−0.1	
29	11	33	12.0	11.3	....	−0.7	....	
29	11	55	11.8	11.2	....	−0.6	....	
May 2	8	42	06.2	....	06.0	....	−0.2	
2	8	58	05.7	....	05.8	....	+0.1	
2	9	12	05.9	05.4	....	−0.5	....	
2	9	26	05.5	05.0	....	−0.5	....	
2	9	50	05.0	....	05.0	....	0.0	Inductor 25 at station *Jarrah Peg;* inductor 3 at station *Brass Pipe*
2	10	07	04.7	....	05.0	....	+0.3	
2	10	34	04.4	....	04.5	....	+0.1	
2	10	51	04.2	03.6	....	−0.6	....	
2	11	05	03.6	03.2	....	−0.4	....	
2	11	40	04.2	....	04.3	....	+0.1	
2	12	00	04.4	....	04.2	....	−0.2	
2	12	16	04.4	03.5	....	−0.9	....	
2	12	32	04.5	03.9	....	−0.6	....	
Mean values for ΔI						−0.52	−0.01	
Mean ΔI for commutator up and down						−0′.3		

[1] The station-difference between the stations *Jarrah Peg* and *Brass Pipe* is 0′.0.
[2] The correction applied to observed values by the inductor attachment of magnetometer-inductor 25, to reduce them to C. I. W. standard, was −0′.5.

TOTAL-INTENSITY OBSERVATIONS.

Sea dip-circle.—Complete specimen observations and computations for total intensity, F, with the sea dip-circle, and the indirect determination of inclination, I, from the deflection observations, are shown on pages 219 and 220. The value of the horizontal intensity, H, is obtained by the formula

$$H = F \cos I$$

As the method employed is a relative one, it is essential that no change be made in the weight used with the loaded-dip needle, and that its position be not shifted from one end of the needle to the other during a cruise; furthermore, the magnetism of the loaded-dip and deflected needles, except for the normal changes with time, must remain unchanged. The reduction formulæ for the total intensity are:

Loaded-dip observations only, $F = C_l \cos I' \csc u$
Deflection observations only, $F = C_d \csc u_1$
Both loaded-dip and deflection observations, $F = C\sqrt{\cos I' \csc u \csc u_1}$

where I' is the loaded-dip angle, u_1 is the deflection angle, $u = I - I'$, C_l is the loaded-dip constant $= \frac{K}{m}$, C_d is the deflected-dip constant $= K_1 m$, and C is the combined constant $= \sqrt{KK_1}$. The constants C_l and C_d involve the magnetic moment, m, of the loaded-dip needle, and are both, therefore, subject to change with temperature and with time. C_l, furthermore, involves the induction correction which is a function of F. C_d is affected also by changes in deflection distances, due to temperature changes, as well as by any changes in the distribution coefficients. Two deflection distances, designated short (S) and long (L), are provided in the modified sea dip-circle (see p. 195), and thus there are two independent sets of constants. In deflection observations there are also two positions of the deflected or suspended magnet, designated "direct" (D) and "reversed" (R); "direct" position means that the face of the deflected needle is towards the face of the vertical circle; "reversed" position means that the face of the deflected needle is towards the back of the vertical circle. For all of the *Carnegie* work the deflection observations were made in both "direct" and "reversed" positions for each determination, and, therefore, the constants to be controlled by shore observations for that work are: C_l, C_{dDR} for S, and C_{dDR} for L. Values of these intensity constants were determined at each shore station and at Washington by means of comparisons between the sea dip-circles and standardized land magnetometers and inclination instruments.

Specimen observations and reductions for the determination of the constants are given on pages 248–250. The specimens are typical of the compilations made for each pair of intensity needles. The order followed in the observations is such that the mean times of the three determinations of constants will be practically the same. The order is as follows: (1) loaded-dip observations, set I; (2) deflected-dip observations for "direct" position and short distance; (3) deflected-dip observations for "direct" position and long distance; (4) deflected-dip observations for "reversed" position and long distance; (5) deflected-dip observations for "reversed" position and short distance; and finally (6) loaded-dip observations, set II.

Because of the development of microscopic rust-pits on the needle pivots there are erratic changes in the intensity constants. It was, therefore, necessary to depend entirely upon graphical adjustments, or upon linear interpolations with time between shore-station values. The method adopted for each cruise is given with the summary of constants (pp. 250–252).

Total Intensity: Loaded-Dip Observations with Sea Dip-Circle at Shore Station

Station: A, Suva Vou, Fiji — *Date:* Mon., June 17, 1912 — *Obs'r:* H. D. F.
Dip Circle: No. 189 — *Needle* No. 8 loaded; wt. 11 — *Chron'r:* No. 51

End of needle marked *A* north up — I

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
124 17 17	304 19 20	55 40 39	235 43 43	55 43 44	235 46 48	124 11 12	304 14 13
55 43.0	55 40.5	55 39.5	55 43.0	55 43.5	55 47.0	55 48.5	55 46.5
−55° 41′.8		−55° 41′.2		−55° 45′.2		−55° 47′.5	
−55° 41′.5				−55° 46′.4			

Mean I_1': −55° 44′.0

End of needle marked *A* north up — II

Circle East		Circle West		Circle West		Circle East	
Needle Face East		Needle Face West		Needle Face East		Needle Face West	
S	N	S	N	S	N	S	N
° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
124 16 17	304 17 18	55 40 38	235 40 40	55 45 46	235 46 48	124 16 15	304 13 15
55 43.5	55 42.5	55 39.0	55 40.0	55 45.5	55 47.0	55 44.5	55 46.0
−55° 43′.0		−55° 39′.5		−55° 46′.2		−55° 45′.2	
−55° 41′.2				−55° 45′.7			

Mean I_2': −55° 43′.4

Mean I' for I and II: −55° 43′.7

Set	Chron. Times I		Chron. Times II		Temperatures I	Temperatures II
	h	*m*	*h*	*m*	°C	°C
Beginning	13	01	13	52	25.6	25.9
Ending	13	10	13	58	25.6	26.2
Means	13	06	13	55	25.6	26.0
Chron. corr. on L. M. T.	0	00	0	00		
Local mean time	13	06	13	55	Mean for sets sets I and II 25°.8	
Mean L. M. T.	13ʰ 30ᵐ					

Magnetic meridian reads 168° 57′ and 348° 57′

Remarks

Magnetic-meridian setting as determined by prime - vertical method with needle 5
Footscrew *C* was north

Total Intensity: Deflection Observations with Sea Dip-Circle at Shore Station

Station: A, Suva Vou, Fiji | *Date:* Mon., June 17, 1912 | *Obs'r:* H. D. F.
Dip Circle: No. 189 | *Needle:* No. 7 suspended, 8 deflecting | *Chron'r:* No. 51

Specimen Determinations of Intensity Constants of Sea Dip-Circle

Station: A and B, Suva Vou, Fiji *Instrument:* Sea dip-circle 189 *Obs'r:* H. D. F.

Station.	Date	Local Mean Time	Inclination, I[1] C. I. W. Standard	Loaded Dip Needle 8, Weight 11			Deflected Dip, Needle 7 Suspended, 8 Deflecting					
							Short Distance			Long Distance		
				Temp.	I'	$u=I-I'$	Temp.	u_{1D}	u_{1R}	Temp.	u_{1D}	u_{1R}
	1912	h	° ′	°C	° ′	° ′	°C	° ′	° ′	°C	° ′	° ′
A	June 17	13.5	−38 29.0	25.8	−55 43.7	17 14.7	25.7	43 03.2	43 09.8	25.8	29 11.8	29 15.0
	17	15.1	−38 28.8	26.4	−55 42.9	17 14.1	26.5	43 01.9	43 07.7	26.5	29 15.7	29 20.4
	18	10.9	−38 27.9	26.0	−55 43.5	17 15.6	26.0	42 59.2	43 04.0	26.0	29 14.2	29 17.9
	18	12.1	−38 28.1	......	....	....	......	....	....	24.7	29 14.5	29 15.4
B	June 19	10.8	−38 27.9	27.0	−55 44.9	17 17.0	27.0	43 01.4	43 11.2	26.9	29 20.0	29 21.4
	19	12.6	−38 28.0	26.5	−55 43.8	17 15.8	26.6	43 00.5	43 12.9	26.2	29 19.0	29 19.8
	19	14.8	−38 27.9	26.5	−55 44.0	17 16.1	26.6	43 02.0	43 06.7	26.7	29 19.5	29 19.2
Means			−38 28.2	26.4	−55 43.8	17 15.6	26.4	43 01.4	43 08.7	26.1	29 16.4	29 18.4

Computations

Loaded-Dip Constant: $C_l = \frac{K}{m} = H \sec I \sin u \sec I'$

Horizontal Intensity,[2] H	0.34693
Log H	9.54024
Log sec I	0.10628
Log sin u	9.47233
Log sec I'	0.24942
Log C_l at $t°$	9.36827

Deflected-Dip Constant: $C_d = K_1 m = H \sec I \sin u_1$

Distance	Short	Long
Mean u_1 for D and R	43° 05′.0	29° 17′.4
Log H ($H = 0.34693$)	9.54024	9.54024
Log sec I	0.10628	0.10628
Log sin u_{DR}	9.83446	9.68951
Log C_{dDR} at $t°$	9.48098	9.33603

[1]From simultaneous inclination-observations, made with earth inductor 2 at station B on June 17 and 18, and at station A on June 19; after reduction to C. I. W. Standard, the values were referred to the dip-circle station by means of the station-difference $(A - B) = -0'.1$.

[2]There were no simultaneous observations for H. The adopted value is the mean of 20 with standardised magnetometers 2 and 4, made at various times from $10^h.9$ to $15^h.5$ on June 11–14, 1912, and referred to the dip-circle stations.

SEA DIP-CIRCLE CORRECTIONS.

The adopted inclination-corrections and intensity-constants are given below for each sea dip-circle. All corrections and constants are on the basis of C. I. W. Standards (see p. 232). For the regular dip-needles, the inclination corrections apply to complete determinations by both polarities, and for the deflected needle, to the mean of determinations made in both "direct" and "reversed" positions. *All inclination values are referred to north-seeking end of needle, inclination of north-seeking end of needle below horizon being reckoned positive. All values of total intensity and horizontal intensity are reckoned positive; values of vertical intensity are given the same sign as the corresponding inclinations.* ΔI and F in the formulæ are always expressed in minutes of arc and in C. G. S. units, respectively.

Sea dip-circle 189.—Sea dip-circle 189, manufactured by Dover, is of the latest pattern (see p. 195). It was used on Cruises I, II, III, and IV, except for March 1915. For Cruise I the adopted inclination-corrections are from a graphical adjustment of observed data at shore stations and of the data derived from the special experimental work at Washington. For Cruise II the adopted inclination-corrections are the means of values of ΔI_1 and ΔI_2, derived by different methods: (1) by a least-square adjustment of all available data for each needle in accordance with the formula

$$F\Delta I_1 = x + z \cos I + y \sin I$$

and (2) by a time interpolation between the observed corrections at the next preceding and next following stations; the adopted correction, $\Delta I = \frac{1}{2}(\Delta I_1 + \Delta I_2)$. For Cruise III the adopted corrections are the means of the values determined at the 4 shore stations where the sea instruments were compared with the standard instruments for control during this cruise.

The adopted inclination-corrections are taken from Table 60.

TABLE 60.—*Inclination Corrections for Sea Dip-Circle 189.*

Cruise I

Inclination	Regular Dip-Needles		Needle No. 7, *D* and *R*, deflected by Needle No. 8	
	No. 9	No. 10	Short Distance	Long Distance
°	′	′	′	′
+75	−6.8	−6.0	+1.4	+1.2
+70	−4.6	−3.9	+3.0	+2.5
+65	−2.8	−1.7	+4.1	+1.6
+60	−1.2	0.0	+5.2	−0.7
+55	+0.2	+1.4	+6.2	−2.5
+50	+1.5	+2.7	+7.2	−2.3
+45	+2.7	+3.8	+8.2	−1.1
+40	+3.5	+5.0	+9.0	+0.5

Cruise II Method 1

Number of		Deflection Distance	Formulæ for ΔI_1
Suspended Needle	Deflecting Needle		
			′ ′ ′
5	..	....	$F\Delta I_1 = -6.0+6.5 \cos I+2.3 \sin I$
9	..	....	$F\Delta I_1 = -3.3+4.6 \cos I+1.4 \sin I$
10	..	....	$F\Delta I_1 = -3.9+3.7 \cos I+1.4 \sin I$
7 *D* and *R*	8	Short	$F\Delta I_1 = -3.4+6.2 \cos I+3.1 \sin I$
7 *D* and *R*	8	Long	$F\Delta I_1 = -6.0+7.5 \cos I+0.0 \sin I$

Cruise II Method 2

Date	Inclination-Correction ΔI_2 for Needle					
	No. 5[1]	No. 6[2]	No. 9	No. 10[1]	No. 7_S[3]	No. 7_L[4]
	′	′	′	′	′	′
1910.44	....	....	− 3	−2	+ 1	+ 2
1910.57	....	....	+ 2	+7	+ 5	− 1
1910.76	....	....	+ 2	+4	+12	− 1
1910.95	....	....	− 2	0	....	+ 2
1911.06	....	....	− 4	+4	....	− 1
1911.26	....	....	+ 1	−1	− 2	−11
1911.48	− 6	−2	+10	−7	+10	− 2
1911.61	+ 7	+8	+ 1	....	− 6	+ 5
1911.70	− 4	....	+ 3	....	+ 4	− 5
1911.83	−13	....	− 2	....	+ 9	−13
1912.13	+16	+5	+ 7	....	−10	+17
1912.46	−16	−2	+ 5	....	+13	−10
1912.72	− 8	....	− 2	....	+82	− 2
1912.92	− 8	....	+10	....	−65	+30
1913.11	+11	....	+12	....	−17	+ 9
1913.33	− 5	....	+ 6	....	....	+50
1913.50	− 7	....	+13	....	....	+11
1913.72	− 5	....	+ 8	....	+ 1	−18
1914.04	− 1	....	+11	....	+ 2	−12

Cruise III

Inclination	Regular Dip-Needles		Needle No. 7, *D* and *R*, deflected by Needle No. 8	
	No. 5	No. 6	Short Distance	Long Distance
....	+2.′8	−1.′8	+0.′6	−5.′2

[1]Needle 5 was substituted for needle 10 in June 1911.
[2]Method 2 only is used for needle 6; this needle was seldom used during Cruise II.
[3]Mean value for needle 7 in "direct" and "reversed" position, deflected by needle 8 at short deflection-distance.
[4]Mean value for needle 7 as for footnote 3, but at long deflection-distance.

The adopted intensity-constants, C_t, C_{dDRS}, and C_{dDRL}, are given in Table 61. For Cruise I they are obtained from a graphical adjustment of all the available data. For Cruises II and III the values in Table 61 are those determined at shore stations for the dates given; for sea stations a direct time interpolation is made between the next preceding and the next following values of the table. The adopted value of the temperature factor, q, is 0.0001 for both log C_t and log C_d. To refer a value at 20° centigrade, taken from Table 61, to the temperature, t, of observations, the following formulæ are used:

$$\log C_{tt} = \log C_{t20} - 0.0001\,(20° - t) \qquad \log C_{dt} = \log C_{d20} + 0.0001\,(20° - t)$$

TABLE 61.—*Intensity Constants at 20° Centigrade (C_{t20} and C_{d20}) for Sea Dip-Circle 189.*

For Cruise	Date	Log C_{t20} for Needle 8 Loaded with Weight 11	Log C_{d20} for Needle 7 Deflected by Needle 8		Date	Log C_{t20} for Needle 8 Loaded with Weight 11	Log C_{d20} for Needle 7 Deflected by Needle 8	
			Short Distance	Long Distance			Short Distance	Long Distance
	1909.58	9.3482	9.4946	9.3485	1909.90	9.3517	9.4911	9.3451
	1909.60	9.3481	9.4946	9.3486	1909.95	9.3526	9.4902	9.3442
	1909.65	9.3481	9.4947	9.3487	1910.00	9.3535	9.4893	9.3433
I	1909.70	9.3484	9.4944	9.3484	1910.05	9.3544	9.4884	9.3424
	1909.75	9.3490	9.4938	9.3478	1910.10	9.3553	9.4875	9.3415
	1909.80	9.3498	9.4929	9.3469	1910.15	9.3562	9.4866	9.3406
	1909.85	9.3508	9.4920	9.3460	....	......	......	......
	1910.44	9.3556	9.4864	9.3407	1912.12	9.3551	9.4810	9.3318
	1910.57	9.3545	9.4852	9.3416	1912.46	9.3676	9.4816	9.3366
	1910.76	9.3565	9.4864	9.3410	1912.72	9.3696	9.4836	9.3328
	1910.95	9.3595	......	9.3350	1912.92	9.3668	9.4770	9.3360
II	1911.06	9.3645	......	9.3346	1913.11	9.3638	9.4760	9.3386
	1911.26	9.3514	9.4811	9.3315	1913.34	9.3738	......	9.3312
	1911.47	9.3550	9.4793	9.3347	1913.50	9.3632	......	9.3310
	1911.61	9.3482	9.4789	9.3339	1913.72	9.3590	9.4706	9.3263
	1911.70	9.3559	9.4783	9.3324	1914.04	9.3568	9.4712	9.3249
	1911.84	9.3624	9.4820	9.3368	....	......	......	......
III	1914.40	9.3591	9.4721	9.3252	1914.66	9.3641	9.4699	9.3203
	1914.53	9.3682	9.4711	9.3218	1914.84	9.3591	9.4687	9.3226

Sea dip-circle 203.—Sea dip-circle 203, manufactured by Dover, is of the latest pattern (see p. 195). It was carried as a reserve instrument and was used only at a few auxiliary land stations during Cruise I; the corrections adopted for these, from intercomparisons with earth inductor 2 and circle 201, are: mean of needles 9 and 10 at dip +67°, −6′.9; at dip +54°, −4′.6; needle 5 at dip +54°, −5′.0. The logarithms of the adopted combined intensity-constant, for needles 7 and 8 (8 loaded with weight 31), in October 1909 are:

Log C for short deflection-distance, 9.55463
Log C for long deflection-distance, 9.48089

CONSTANTS AND CORRECTIONS FOR LAND INSTRUMENTS.

DESCRIPTIONS OF MAGNETOMETERS, DIP CIRCLES, AND EARTH INDUCTORS.

The reduction formulæ and methods of determining constants for the land instruments used in the *Carnegie* shore work and in the standardization of the ocean instruments during 1909–1916 were the same as those in Volume I (pp. 22–41).

The types of magnetometers used are described and illustrated in Volumes I (pp. 2–7) and II (pp. 5–12); the details respecting them, and the adopted constants for the period 1909–1916, are shown in Table 62.

Magnetometers 2, 3, 4, 5, and 8 were manufactured by the Bausch and Lomb Optical Company of Rochester, New York; the magnets are hollow cylinders, the long magnets

being 7.5 cm. long, with inside diameter of 0.75 cm. and outside diameter of 1.00 cm., and the short magnets being 3.5 cm. long, with inside diameter of 0.61 cm. and outside diameter of 0.82 cm. Universal magnetometers 14, 19, and 21, and magnetometer-inductor 25 were designed and constructed by the Department of Terrestrial Magnetism; the magnets are hollow cylinders, the long magnets being 5.6 cm. long, with inside diameter of 0.60 cm. and outside diameter of 0.79 cm., and the short magnets being 2.6 cm. long, with inside diameter of 0.45 cm. and outside diameter of 0.65 cm. Phosphor-bronze-ribbon suspensions were used for all these instruments.

TABLE 62.—*Details and Constants of Magnetometers Used, 1909–1914.*

[The c. g. s. system of units is used throughout the table; the value of q is given for 1° C.]

No.	Type	Diameter Hori-zontal Circle	Moments of Long Magnets at 20° C.		Distribution Coefficients		Induc-tion Coeffi-cient h	Tempera-ture Coeffi-cient q	Scale Value for Declina-tion	Deflection Distances Used	Constants Apply for Period
			Inertia	Magnetic	P	Q					
		cm.							′	*cm.*	
2	1 (*a*)	12.5	162	615	+15.78	−1000	0.0116	0.00035	1.50	25, 27.5, 30, 35, 40	Sept. 1909 to Dec. 1913
3[1]	1 (*a*)	12.5	166	665	+10.71	+1000	0.0088	0.00041	1.49	25, 27.5, 30, 35, 40	1909 to 1914
4	1 (*a*)	12.5	156	625	+14.87	− 881	0.0116	0.00035	1.49	25, 27.5, 30, 35, 40	Sept. 1909 to Dec. 1913
5	1 (*a*)	12.5	234	620	+15.56	− 570	0.0063	0.00046	1.48	25, 27.5, 30, 35, 40	June 1914 to Oct. 1914
8	1 (*a*)	12.5	237	507	+14.67	+ 24	0.0063	0.00037	1.48	25, 27.5, 30, 35, 40	March 1911
14	4 (*b*)	10.1	66	280	+ 7.81[2]	....	0.0093	0.00060	1.95	20, 25, 28	Apr. to Sept. 1913
19	4 (*b*)	12.0	65	285	+ 7.60[2]	....	0.0091	0.00048	2.15	20, 25, 28	Sept 1912 to May 1913
25	4 (*c*)	10.2	65	305	+ 7.54[2]	....	0.0095	0.00044	1.97	20, 25, 28	June 1914 to Oct. 1914

[1]Magnetometer 3 is the standard magnetometer of the Department of Terrestrial Magnetism.
[2]This value of P is the value of P', assuming that $(1 + P'r^{-2}) = (1 + Pr^{-2} + Qr^{-4})$.

The *dip-circles and universal magnetometers used* to determine inclination at shore stations were of the patterns which are fully described and illustrated in Volumes I (pp. 7–10) and II (pp. 7–9), viz: (*a*) the regular Kew land-pattern as made by Dover; (*b*) the sea dip-circle pattern (see p. 195) as made by Dover, and which was used for Cruise I; and the dip-circle attachment of the universal-magnetometer pattern, 4 (*b*), designed and constructed by the Department of Terrestrial Magnetism. To determine the magnetic declination at shore stations, a compass attachment, fully described and illustrated in Volume I (p. 9), was provided for each land and sea dip-circle. (See also this volume, pp. 21-23).

The *earth inductors used* to determine the inclination at shore stations were of the patterns which are fully described and illustrated in Volumes I (pp. 10–11) and II (pp. 9–15), and in this volume (pp. 196–200), viz: (*a*) the Wild-Eschenhagen pattern as made by Schulze and by Toepfer & Sohn; (*b*) the marine pattern, and the earth-inductor attachment of the magnetometer-inductor pattern, 4 (*c*); the last two types were designed and constructed by the Department of Terrestrial Magnetism. Earth-inductor 48, constructed by Schulze, and fully described and illustrated in Volume I (pp. 10–11), was the standard inclination instrument of the Department of Terrestrial Magnetism during 1909–1916.

MAGNETOMETER CORRECTIONS.

The corrections of each magnetometer on the adopted standard (see p. 232), were determined at Washington, before and after field use of the instrument and also in the field, whenever possible, by means of comparisons with other magnetometers. The accuracy of the mean corrections for the land instruments is usually about 0′.2 in declination, and about 0.0001H in horizontal intensity. The tabulated corrections are to be applied algebraically, east declination being reckoned as positive and west declination as negative; horizontal intensity is always taken as positive.

The tabulated H-corrections are those actually applied in the final reductions of the observations, except for magnetometers 5, 14, 19, and 25, for which the values as given in Table 63 are the equivalent corrections on the basis of the finally adopted distribution coefficients given in Table 62, instead of the distribution coefficients first adopted and used in the original computations and revisions.

TABLE 63.—*Magnetometer Corrections on Adopted C. I. W. Standards for the Period 1909–1914.*

No. of Magnetometer	Correction to Observed		Remarks
	Declination	Horizontal Intensity	
	′		
2	+0.2	−0.00030H	To December 1910
2	+0.1	−0.00010H	From January 1911 to December 1913
3	0.0	+0.00015H	Standard magnetometer
4	+0.5	+0.00020H	From September 1909 to February 1910
4	+0.4	+0.00024H	From March 1910 to December 1913
5	−0.7	−0.00081H	From June 1914 to October 1914
8	+0.1	−0.00017H	March 1911
14	−0.7	+0.00028H	From April to September 1913
19	−0.2	+0.00039H	From September 1912 to May 1913
25	−0.4	+0.00026H	From June 1914 to October 1914

DIP-CIRCLE CORRECTIONS.

In the regular inclination-observations at shore stations, the polarity of the needles is invariably reversed, and, hence, the so-called balance error caused by any eccentricity of the center of gravity of the needle is eliminated. There remains, however, the error caused by any irregularity of the figure of the pivot, and this will vary, in general, with the magnetic field. The correction data from all comparisons at Washington, in the field, and at observatories are utilized to determine for each needle an equation expressing the variation of the correction, ΔI, with total intensity, F, and inclination, I, of the general form (see Volume I, p. 45, Volume II, p. 17, and this volume, p. 250):

$$F\Delta I = x + z\cos I + y\sin I$$

In the cases, however, where only a few reliable comparisons are available, and particularly in the tropics, where, because of the development of rust, a rapid deterioration of the dip needles is encountered, it has been necessary to depend for the corrections on a critical study of the differences exhibited by the needles among themselves, and then to work back from these differences to the base-station corrections.

The adopted dip-corrections for the land dip-circles are given separately for each instrument; they are to be applied algebraically, inclination of the north-seeking end of the needle below the horizon being regarded as positive, and *vice versa*. In case of the shore stations of Cruise I, for which values obtained with the sea dip-circles are utilized in the Table of Results for shore stations, the corrections given in Table 60 and on pages 255–256 were applied. The declination corrections adopted for the dip-circle compass

attachments follow the inclination corrections; the declination corrections adopted for the compass attachments of the sea dip-circles are given on page 256.

Universal magnetometer 14.—Universal magnetometer 14, designed and constructed by the Department of Terrestrial Magnetism, was used during April to September 1913 on Cruise II. The adopted inclination-corrections are given in Table 64.

TABLE 64.—*Inclination Corrections for Universal Magnetometer 14.*

Inclination	Correction for Dip Needle			
	No. 1	No. 2	No. 5	No. 6
°	′	′	′	′
+70	+0.3	+1.6	+0.9	+0.5
+60	+0.1	+1.2	+0.8	+0.3
+50	−0.2	+0.5	+0.5	−0.1
+10	−0.8	−1.9	−0.6	−1.2
0	−0.3	−2.3	−0.8	−1.4
−10	+0.3	−2.6	−1.1	−1.5
−20	+0.8	−2.7	−1.4	−1.7

Universal magnetometer 19.—Universal magnetometer 19, designed and constructed by the Department of Terrestrial Magnetism, was used during September 1912 to May 1913 on Cruise II. The adopted inclination-corrections are given in Table 65.

TABLE 65.—*Inclination Corrections for Universal Magnetometer 19.*

Inclination	Correction for Dip Needle				Remarks
	No. 1	No. 2	No. 5	No. 6	
°	′	′	′	′	
+70	−0.4	+0.9	−0.2	−1.3	Needles 1 and 5 are somewhat erratic in behavior, and frequently results with them have had to be rejected on that account; this has been particularly the case for inclinations from −14° to −20°
0	−0.1	+0.6	−1.0	−1.0	
− 4	+3.0	−0.2	−0.5	−0.6	
− 8	+5.9	−1.0	−0.2	−0.3	
−12	+8.1	−1.2	0.0	−0.1	
−16	+8.7	−1.1	−0.1	−0.1	
−20	+6.1	−0.6	−0.9	+0.2	
−24	+3.0	+0.2	−2.5	+0.8	
−28	+2.7	−1.2	−2.9	+1.0	
−32	+3.6	−2.4	−2.5	+0.8	
−36	+4.1	−1.8	−2.3	−0.1	

Land dip-circle 178.—Circle 178, manufactured by Dover, was used during Cruise I. While on board the *Carnegie* the needle pivots deteriorated rapidly, so that very few available results were obtained. The adopted inclination-corrections are those determined from least-square adjustments of data obtained during 1908 and 1909, prior to the *Carnegie* work, and are given by the formulæ:

$$\begin{array}{ll} \text{Needle 1} & F\Delta I = +0'.2+0'.4\cos I+0'.5\sin I \\ \text{Needle 2} & F\Delta I = +0.3-0.4\cos I-0.1\sin I \\ \text{Needle 5} & F\Delta I = +0.2-1.0\cos I+0.3\sin I \\ \text{Needle 6} & F\Delta I = +0.4+1.2\cos I+0.3\sin I \end{array}$$

The adopted correction for observed declinations by the compass attachment is $+1'.2$.

Land dip-circle 201.—Circle 201, manufactured by Dover, was used during Cruises I and II. The adopted inclination-corrections are as follows:

Cruises I and II (to December 1910):

Needle 1 $F\Delta I = -0'.4 + 0'.9 \cos I - 0'.3 \sin I$
Needle 2 $F\Delta I = -1.9 + 2.6 \cos I + 0.4 \sin I$

Cruise II (from January 1910):

Needle 1 $F\Delta I = -0'.3 + 0'.8 \cos I - 0'.4 \sin I$
Needle 2 $F\Delta I = -1.6 + 1.9 \cos I + 0.2 \sin I$
Needle 5[1] $\Delta I = -1.3$ for $I = -5°$
$\Delta I = +2.0$ for $I = -30°$ to $-45°$
Needle 6[1] $\Delta I = +2.3$ for $I = -5°$

The adopted correction for observed declination by the compass attachment is $-4'.6$ for Cruises I and II.

Sea dip-circles 189 and 203.—The adopted inclination-corrections for the sea and shore work during Cruises I, II, and III, are given on pages 251–252.

The adopted corrections for observed declinations by the compass attachments are:

For circle 189 on Cruises I and II	$+6'$ when mark readings are made with peep sights.
For circle 203 on Cruise I	$+1'$ when mark readings are made with telescope or with peep sights.
For circle 203 on Cruise II	$-1'$ when mark readings are made with telescope.

EARTH-INDUCTOR CORRECTIONS.

The numerous comparisons made with earth inductors by the observers of the Department of Terrestrial Magnetism, in various regions of the globe, have indicated that the correction of an earth inductor on standard is subject to practically no change with change in magnetic field. The adopted inclination-corrections for the inductors are given separately for each instrument; they are to be applied algebraically, inclination of the north-seeking end of the needle below the horizon being regarded as positive, and *vice versa*.

Earth inductor 2.—Inductor 2 of the Wild-Eschenhagen pattern, manufactured by Toepfer und Sohn, and modified somewhat by the Department of Terrestrial Magnetism, was used on Cruise II from September 1910. The adopted inclination-correction is $-0'.7$.

Marine earth-inductor 3.—Values at shore stations by inductor 3, designed and constructed by the Department of Terrestrial Magnetism, were used to strengthen inclination determinations for some stations. The adopted inclination-correction is the same as that used for the sea work, viz, $-1'.0$.

Magnetometer-inductor 25.—The inductor attachment of magnetometer-inductor 25, designed and constructed by the Department of Terrestrial Magnetism, was used at shore stations on Cruises III and IV. The adopted inclination-correction is $-0'.5$.

[1] Needles 5 and 6 were used only at 2 stations.

OCEAN MAGNETIC OBSERVATIONS ON THE CARNEGIE, 1909-1916.

EXPLANATORY REMARKS FOR FINAL RESULTS, 1909-1914.

The same conventions, as nearly as possible, have been followed in the presentation of the ocean magnetic results obtained on the *Carnegie* during the 5 years, August 1909 to October 1914, as adopted for the land results in Volumes I and II.

Stations.—It will be seen that the results are tabulated separately for each of the cruises of the *Carnegie*, and for each ocean. Next under each cruise the stations or points at which the observations were made are arranged chronologically, and they are numbered accordingly. Thus for Cruise I, the stations are numbered beginning with 1CI (Station 1, *Carnegie* Cruise I). For Cruise II, the numbering proceeds chronologically, beginning with 1CII (Station 1, *Carnegie* Cruise II). Similarly for Cruise III, the first station is 1CIII.

Geographic positions.—The second and third columns contain, respectively, the latitude and longitude (counted east from Greenwich), expressed in degrees and the nearest minute of arc. The latitudes and longitudes for the points of observation at sea were determined in accordance with the methods described on pages 225–231; in general they may be regarded as correct within 2 or 3 nautical miles. When no astronomical observations were possible for several days the error in latitude or longitude may amount to 5, or even 10 miles, dependent upon circumstances. The geographic positions of the harbor stations are in general known within 1′ of latitude and longitude.

Date.—The date on which the magnetic observations were made is recorded in the fourth column. The following abbreviations have been adopted for the months of the year: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec. The year is indicated at the head of the column.

Magnetic elements.—The values of the magnetic elements (declination, inclination, and horizontal intensity) will be found in the next columns as observed at the local mean time (L. M. T.), expressed to nearest 0.1 of an hour, opposite each value. Occasionally it has appeared desirable, where diurnal variation in declination was observed, as, for example, in connection with the shore results on pages 296–309, or where numerous observations were made during a certain interval, as during a vessel swing, to give the local mean times of the beginning and of the end of the series, and to indicate for land results the number of determinations from which the mean value is derived by a number inclosed in parentheses, thus, $9^h.1$ to $11^h.3$(7) is to be read "the mean is the result of 7 determinations made during the interval $9^h.1$ to $11^h.3$, local mean time, inclusive;" $6^h.1$ to $20^h.3$ (dv) is to be read "eye readings of the suspended magnet were made regularly at short intervals from $6^h.1$ to $20^h.3$, local mean time." The local mean times are given according to civil reckoning and are counted from midnight as zero hour continuously through 24 hours; 16^h, for example, means 4 o'clock p. m.

The ocean values of magnetic declination and of inclination are given in degrees and minutes of arc. No claim, however, is made that they are correct to a minute of arc. In general the error in the tabulated value is about 5′ to 10′ or less; in some cases the error may be more, dependent upon the severity of the conditions encountered during the observations. It was thought best to retain the original quantities resulting from the computations until the various corrections, mentioned below, have been applied.

Only the mean quantities resulting from the observations with all instruments used for any particular element are given.

The values of the horizontal intensity, derived as exemplified on pages 216–220, 236, and 247, with all instruments employed, are tabulated to the fourth decimal of the C. G. S. unit of magnetic field intensity. In magnetic-survey work on land the fourth decimal is often uncertain by one or more units, and in ocean work the error may be five or more

units in this decimal place. It is thus to be understood that no claim is made for the correctness of the last figure; it has been retained here primarily in order that when all reductions to common epoch have been applied on account of the various magnetic variations, the error of computation will be kept within the desired limit.

The question whether to give values of the horizontal intensity exclusively, or values of total intensity, was decided in the previous volumes, for the practical reasons there stated, in favor of the former.

The *instruments* used are shown in the columns "Compass" and "Dip Circle." The designations of the various instruments employed will be found stated on pages 203–211. The term "Compass" also includes the "Sea Deflector" with which both declinations and horizontal intensities were observed, as described on pages 190–195. The term "Dip Circle" also includes the "Marine Earth-Inductor," and the "Sea Dip-Circle" when arranged for measurement of the total intensity. The designation 189.9,10,*78* means that inclination was observed with sea dip-circle 189, using regular dip needles 9 and 10 and deflected needle 7, and that, furthermore, total intensity was obtained by the deflection method, using intensity needles 7 and 8. Invariably the intensity needles are italicized and are given last. The higher number of the two intensity needles always designates the chief intensity needle (the deflecting and the loaded needle). Whenever the total intensity was determined from both loaded-dip observations and deflections, this fact is shown by the addition of the dagger (†); thus, *e. g.*, 189.9,10,*78*†. By turning to the specimens of observations, pages 212–225, any additional explanation required may be obtained.

The columns of "Remarks" contain:

a. Course.—This is the ship's magnetic course (heading) on which the observations were made. When the word "swing" occurs, this means that the vessel was swung during observations, to test occasionally the absence of deviation corrections. For all swings, the local mean times given in the respective columns denote the times of beginning and ending of the swing.

On the *Carnegie*, because of the absence of deviation corrections, it was also possible to make observations when the vessel's heading was shifting, as would be the case when the vessel was "becalmed" or "at anchor."

b. Roll.—This column records the full angle through which the ship rolled, from side to side.

c. Sea.—The state of the sea is indicated by the following symbols:

B. Broken or irregular sea.	*H*. Heavy sea.	*R*. Rough sea.
C. Chopping, short, or cross sea.	*L*. Long rolling sea.	*S*. Smooth sea.
G. Ground swell.	*M*. Moderate sea, or swell.	*T*. Tide rips.

Sometimes the combinations of symbols in the observers' records denoting the state of the sea appear incongruous. In these cases one particular letter was selected, after a careful consideration of all the symbols given by the various observers, supplemented by the recorded ship's roll and by other notes.

d. Weather.—The symbols denoting the state of the weather at the time are those in general use:

b. Clear, blue sky.	*l*. Lightning.	*s*. Snow.
c. Clouds.	*m*. Misty.	*t*. Thunder.
d. Drizzling or light rain.	*o*. Overcast.	*u*. Ugly appearances, threatening weather.
f. Fog or foggy weather.	*p*. Passing showers.	*v*. Variable weather.
g. Gloomy, dark, stormy.	*q*. Squally.	*w*. Wet or heavy dew.
h. Hail.	*r*. Rain.	*z*. Hazy weather.

Weights.—The figures given in the column marked "Wt." are the weights assigned the results on the following scale, which expresses, in a general way, the conditions (sea and weather) under which the observations were made: 1 denotes severe or adverse conditions, 2 medium, and 3 favorable conditions.

The application of variation corrections to the observed results on account of the numerous variations of the Earth's magnetism, *e. g.*, diurnal variation, secular variation, magnetic perturbations, etc., is deferred to the volume in which all the magnetic data, obtained both on land and sea, are summarized and reduced to a common epoch. (That volume, probably No. V, can not appear until some time after the completion in 1917 of the *Carnegie's* present cruise. Whether it will be worth while, in the case of the ocean data, to apply any other corrections than those on account of secular change will there receive consideration.) To avoid undue delay in the promulgation of the accumulated data, and in view of the inaccuracies of the magnetic charts at present in use, it is considered best to publish the observed results as obtained with no corrections applied except the reductions to magnetic standards, as fully explained in the section on this subject (see pp. 232–256). However, since for the magnetic elements tabulated the precise date and local mean time of each observation are given, the reader is supplied with the required information in case, for some purpose of his own, he desires to reduce the observed values to some mean time.

COMBINING WEIGHTS ASSIGNED TO DIFFERENT INSTRUMENTS AND METHODS.

The tabulated values of the magnetic elements are the weighted means, usually of two or more results, obtained with two different instruments, or by two different methods.

To obtain the weighted mean value of the declination, the results with the standard compass (marine collimating-compass, C1) were given a combining weight 2, whereas the auxiliary results with sea deflector (D3, D4) received the weight 1.

The weighted mean value of the inclination was obtained by assigning the weight 2 to the result from each dip needle and the weight 1 to the result derived from each complete observation of deflected dip. Hence, the inclination results from long and short distance each received a weight of 1, or if the observation at one distance was repeated, the result was given a weight of 2. At the stations where the inclination was determined both with the dip circle and the earth inductor, the dip-circle result, obtained as just described, was, in general, combined with the earth-inductor result by giving equal weights to the two instruments. When these two results differed by more than 0°.2, the dip circle was given weight 2 and the earth inductor weight 1. While the earth inductor on land gives results superior to those of the dip circle, certain difficulties enter in marine-inductor work which have not yet been entirely overcome.

The weighted mean value of the horizontal-intensity results was obtained by assigning weights 3, 2, and 1 to the sea-deflector results, the sea dip-circle results by deflections, and the sea dip-circle results by loaded needle, respectively, when the various results were obtained under normal sea conditions. But when the observations were made under unfavorable conditions of motion or with small values of horizontal intensity, the weights assigned were then 6, 4, 1, in the order designated. In some exceptional cases equal weights were assigned the results obtained by sea deflector and by sea dip-circle (deflected dip or loaded dip), as in the case of swings, exceptionally quiet conditions, etc.

The weights referred to above are not to be confused with the figures which appear in the "Wt." columns of the Table of Results. The tabular weights refer to the conditions as to sea and weather under which the observations were made (see p. 258).

EXPLANATORY REMARKS FOR PRELIMINARY RESULTS, 1915–1916, CRUISE IV.

To meet the requests received from various hydrographic establishments, it has been decided to give in this volume, in addition to the final results of the ocean magnetic work on the *Galilee* and the *Carnegie*, 1905–1914, the preliminary results for the subsequent work. These preliminary values of the magnetic elements are derived from computations made and checked aboard the vessel, and are dependent upon preliminary values of instrumental constants. Accordingly, they are subject to future revision when the office computations are made with the final instrumental constants. It is not probable, however,

that there will be many cases in which the values of declination, or of inclination, will be changed by more than 0°.1, and the values of the horizontal intensity by more than 0.001 C. G. S. Since the errors of the present magnetic charts are many times greater than the possible corrections mentioned, the preliminary values here published will answer all practical requirements. As will be seen, the tables (pp. 288–295) apply to the present cruise (IV) and extend up to the arrival of the *Carnegie* at San Francisco, September 21, 1916. For the reasons stated, the values of the magnetic declination and of the inclination are tabulated only to the nearest 0°.1, and the values of the horizontal intensity to the nearest 0.001 C. G. S.

DISTRIBUTION OF STATIONS, 1909–1916.

The following table shows for each cruise of the *Carnegie* the number of days at sea, the length of the cruise in nautical miles, the number of tabulated values, respectively, of declination, inclination, and horizontal intensity; next the average time interval as well as the average distance apart between the observations. It will be seen that there has been a steady increase in efficiency as the work has advanced, the average time interval and the average distance apart of the observations being both less for the later cruises than for the first. For the total length of cruises, up to end of September 1916 (160,615 nautical miles), the magnetic observations, whether of declination, inclination, or horizontal intensity, were made practically every day at an average distance apart of 93 to 138 miles.

TABLE 66.—*Summary showing the Distribution of the Carnegie Magnetic Observations, 1909–1916 (September).*

Cruise	Number		Number of Stations			Average Time Interval			Average Distance Apart		
	Days	Miles	Decl'n	Incl'n	Hor. Int.	Decl'n	Incl'n	Hor. Int.	Decl'n	Incl'n	Hor. Int.
						d	*d*	*d*	*Miles*	*Miles*	*Miles*
I, 1909–10.....	96	9,600	98	68	69	1.0	1.4	1.4	98	141	139
II, 1910–13.....	798	92,829	858	648	643	0.9	1.2	1.2	108	143	144
III, 1914........	84	9,560	108	81	80	0.8	1.0	1.0	89	118	119
IV, 1915–16.....	375	48,626	665	369	368	0.6	1.0	1.0	73	132	132
I, II, III, and IV	1,353	160,615	1,729	1,166	1,160	0.8	1.2	1.2	93	138	138

OBSERVERS AND COMPUTERS.

The Table of Ocean Results differs from the Table of Land Results, published in Volumes I and II, in one other respect besides those already stated in the foregoing explanations, namely, that the observers' initials, for practical reasons, had to be omitted. The magnetic results for any one day are the combined product of all the observers aboard at the time. Those who took part in the observations for the various cruises are as follows:

Carnegie, Cruise I.—J. P. Ault, L. A. Bauer, C. C. Craft, E. Kidson, W. J. Peters, and R. R. Tafel.

Carnegie, Cruise II.—L. A. Bauer, C. C. Craft, H. M. W. Edmonds, E. Kidson, H. D. Frary, C. W. Hewlett, H. F. Johnston, W. J. Peters, and H. R. Schmitt.

Carnegie, Cruise III.—J. P. Ault, H. M. W. Edmonds, H. F. Johnston, and I. A. Luke.

Carnegie, Cruise IV.—J. P. Ault, H. M. W. Edmonds, H. F. Johnston, B. Jones, I. A. Luke, F. C. Loring, and H. E. Sawyer.

The chief persons who have taken part, at various times, in the determination of instrumental constants and comparisons at Washington in the final office reductions, or in the preparation of results for publication, are: *J. P. Ault*, *L. A. Bauer*, J. J. Carey, C. C. Craft, *C. R. Duvall*, H. M. W. Edmonds, *C. C. Ennis*, *H. W. Fisk*, *J. A. Fleming*, H. D. Harradon, H. F. Johnston, E. Kidson, R. R. Mills, J. H. Millsaps, *W. J. Peters*, A. D. Power, H. R. Schmitt, and J. A. Widmer. Those whose names are italicized have borne the chief brunt of the work at Washington.

RESULTS OF OCEAN MAGNETIC OBSERVATIONS ON THE CARNEGIE, 1909-1914.

CRUISE I. ATLANTIC OCEAN, 1909-1910

[illegible] The values of the magnetic elements given have been referred to the [illegible] of the [illegible] with the aid of the Falmouth Observatory records [illegible]. From September 28 to October 3 the Carnegie was at St. John's, Newfoundland. [illegible] November [illegible] the Carnegie was at Falmouth, England.

CRUISE I, ATLANTIC OCEAN, 1909–1910—*Continued.*

[1]From November 25 to December 1 the *Carnegie* was at Funchal, Madeira.

CRUISE I, ATLANTIC OCEAN, 1909–1910—*Concluded.*

CRUISE II, ATLANTIC OCEAN, 1910–1911.

turbance. [1]From January 8 to January 24 the *Carnegie* was at Hamilton, Bermuda. [2]Station 155C1, owing to unfavorable observing conditions, was rejected.

CRUISE II, ATLANTIC OCEAN, 1910–1911—*Continued.*

[1]From July 25 to August 17 the *Carnegie* was at Culebra Island, Port Mulas, and San Juan, Porto Rico.

CRUISE II. OCEAN, 1910-1911

CRUISE II, OCEAN,

[1]From December 2 to 29 the *Carnegie* was at Rio de Janeiro.

[2]From January 14 to 15 the *Carnegie* was at Montevideo.

CRUISE II, ATLANTIC OCEAN, 1910–1911—*Concluded.*

CRUISE II, INDIAN OCEAN, 1911.

[1]From January 18 to February 13 the *Carnegie* was at Buenos Aires.

[2]From March 21 to April 26 the *Carnegie* was at Cape Town.

CRUISE II, INDIAN OCEAN, 1911—*Continued.*

[1]Observations made on opposite courses to eliminate level-error. [2]From June 7 to July 6 the *Carnegie* was at Colombo, Ceylon.

CRUISE II, INDIAN OCEAN, 1911—*Continued.*

[a]Local disturbance; from August 6 to August 15 the *Carnegie* was at Port Louis, Mauritius.

CRUISE II, INDIAN OCEAN, 1911—*Continued.*

[1]From September 10 to September 15 the *Carnegie* was at Colombo, Ceylon.

CRUISE II, INDIAN OCEAN,[1] 1911—*Continued.*

[1]Stations 514CII to 540CII are in the Malay Archipelago.

[2]From October 27 to November 20 the *Carnegie* was at Batavia.

CRUISE II, INDIAN OCEAN, 1911—*Concluded.*

CRUISE II, PACIFIC OCEAN,[1] 1911–1913.

[a]Local disturbance; at anchor in Salayar Strait.

[1]Stations 607 CII to 640 CII are in the Malay Archipelago.

Cruise II, PACIFIC OCEAN,[1] 1911-1913—*Continued*

[illegible]

CRUISE II, PACIFIC OCEAN, 191

CRUISE II, PACIFIC OCEAN, 1911-1912—*Continued*

CRUISE II, PACIFIC OCEAN, 1911–1913—*Continued.*

Cruise II, PACIFIC OCEAN, 1911–1913—*Continued.*

[1]From September 12 to October 15 the *Carnegie* was at Papeete, Tahiti.

Cruise II, PACIFIC OCEAN, 1911-1913—*Continued.*

CRUISE II, PACIFIC OCEAN, 1911–1913—*Concluded.*

[1] From November 26 to December 19 the *Carnegie* was at Coronel and Talcahuano, Chile.

CRUISE II, ATLANTIC OCEAN, 1913.

[1]From January 28 to February 21 the *Carnegie* was at Port Stanley, Falkland Islands.

Cruise II. OCEAN.

CRUISE II, ATLANTIC OCEAN, 1913—*Continued.*

[1] From June 24 to July 20 the *Carnegie* was at Jamestown, St. Helena.

CRUISE II, ATLANTIC OCEAN, 1913—*Continued.*

CRUISE II, ATLANTIC OCEAN, 1913—*Continued.*

*Slight local disturbance; not safe to determine secular changes by comparison with values at station 42CI, page 281.
[1]From September 12 to October 15 the *Carnegie* was at Falmouth, England.

CRUISE II, ATLANTIC OCEAN, 1912—Concluded

[illegible]		Inclination			Hor. Intensity			Instruments		Remarks			
Value	Wt.	L. M. T.	Value	Wt.	L. M. T.	Value	Wt.	Compass	Dip Circle	Course	Roll	Sea	Weather
		h	°		h	c.g.s.					°		
		14.6	69 27 N	2	16.7	[illegible]	1	D6	[illegible]	NW	7	[illegible]	[illegible]
		14.9	69 34 N	2	14.9	[illegible]	1	D6	[illegible]	[illegible]	10	[illegible]	[illegible]
53 W	2							C1 D6		[illegible]	10	[illegible]	[illegible]
		14.6	69 30 N	2	14.8	[illegible]	2	D6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		14.2	69 45 N	2	14.2	[illegible]	2	D6	[illegible]	[illegible]	13		[illegible]
07 W	2							C1 D6		[illegible]		[illegible]	[illegible]
		14.2	69 30 N	2	14.2	[illegible]	2	D6	[illegible]	NW	[illegible]	[illegible]	[illegible]
		14.6	71 26 N	2	14.6	[illegible]	2	D6	[illegible]	W	[illegible]	[illegible]	[illegible]
20 W	2							C1 D6		[illegible]	11	[illegible]	[illegible]
		13.0	70 11 N	2	13.0	[illegible]	2	D6	[illegible]	[illegible]	11	[illegible]	[illegible]
		14.9	71 43 N	2	14.9	1010	2	D6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44 W	2							C1 D6		[illegible]	[illegible]	[illegible]	[illegible]
13 W	2							C1 D6		[illegible]	[illegible]	[illegible]	[illegible]
00 W	1							C1 D6		[illegible]	[illegible]	[illegible]	[illegible]
		12.3 to 16.3	72 00 N	1	12.4 to 16.3	[illegible]	2	D6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		13.6	72 01 N	2	13.6	[illegible]	2	D6	[illegible]	W	[illegible]	[illegible]	[illegible]

CRUISE III, ATLANTIC OCEAN, 1914

CRUISE III, ATLANTIC OCEAN, 1914—*Continued.*

disturbance.

[1]From July 3 to July 25 the *Carnegie* was at Hammerfest, Norway.

[2]From August 24 to September 13 the *Carnegie* was at Reykjavik Iceland.

CRUISE III, OCEAN,

disturbance. [2]Hove to in gale. Stations 142CIII and 143CIII, having the same geographic position, were combined.
[illegible]CIII and 169CIII were combined. [3]From October 12 to October 14 the *Carnegie* was anchored at Greenport, N. Y. [4]Gardiners Bay. [5]Long Island Sound.

PRELIMINARY RESULTS OF OCEAN MAGNETIC OBSERVATIONS ON THE CARNEGIE, 1915-1916.

Cruise IV, ATLANTIC OCEAN, 1915.

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.	Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	*1915*	°	°	*c.g.s.*		° ′	° ′	*1915*	°	°	*c.g.s.*
0CIV[1]	41 06 N	287 47	Mar 7,8	12.0 W	72.2 N	.180	23CIV	22 02 N	293 14	Mar 17	....	55.2 N	.272
1CIV	40 38 N	288 12	Mar 9	....	72.1 N	.180	24CIV	21 50 N	293 23	Mar 17	4.2 W	....	......
2CIV	40 23 N	288 12	Mar 9	11.3 W	....	......	25CIV	20 57 N	293 21	Mar 18	4.0 W	....	......
3CIV[2]	37 48 N	288 15	Mar 10	9.4 W	....	......	26CIV	20 23 N	293 08	Mar 18	....	53.2 N	.281
4CIV[3]	36 37 N	288 26	Mar 10	....	69.3 N	.204	27CIV	18 43 N	292 13	Mar 19	3.3 W	....	......
6CIV	34 17 N	288 33	Mar 11	7.5 W	....	......	28CIV	18 00 N	291 28	Mar 19	....	50.3 N	.291
7CIV	33 20 N	288 26	Mar 11	....	66.4 N	.224	29CIV	17 46 N	291 07	Mar 19	1.6 W	....	......
8CIV	33 05 N	288 25	Mar 11	6.8 W	....	......	30CIV	17 04 N	289 57	Mar 20	0.9 W	....	......
9CIV	31 28 N	288 19	Mar 12	5.8 W	....	......	31CIV	16 42 N	289 20	Mar 20	....	48.3 N	.295
10CIV	30 25 N	288 06	Mar 12	....	63.3 N	.242	32CIV	16 31 N	289 03	Mar 20	0.2 W	....	......
11CIV	30 09 N	288 01	Mar 12	4.8 W	....	......	33CIV	15 37 N	287 44	Mar 21	0.7 E	....	......
12CIV	28 26 N	288 27	Mar 13	4.2 W	....	......	34CIV	15 04 N	286 57	Mar 21	....	45.9 N	.302
13CIV	27 38 N	288 53	Mar 13	....	60.7 N	.255	35CIV	14 52 N	286 37	Mar 21	1.3 E	....	......
14CIV	27 23 N	289 00	Mar 13	4.1 W	....	......	36CIV	13 53 N	285 10	Mar 22	2.0 E	....	......
15CIV	26 28 N	289 19	Mar 14	....	59.6 N	.260	37CIV	13 20 N	284 24	Mar 22	....	42.6 N	.313
16CIV	24 44 N	289 58	Mar 15	3.6 W	....	......	38CIV	12 17 N	282 51	Mar 23	3.1 E	....	......
17CIV	23 46 N	290 34	Mar 15	....	56.9 N	.269	39CIV	11 55 N	282 18	Mar 23	....	40.5 N	.315
18CIV	23 29 N	290 43	Mar 15	2.6 W	....	......	40CIV	11 51 N	282 12	Mar 23	....	40.2 N	......
19CIV	23 01 N	290 48	Mar 16	2.6 W	....	......	41CIV	11 44 N	282 02	Mar 23	3.8 E	....	......
20CIV	22 54 N	290 49	Mar 16	....	55.8 N	.273	42CIV	10 51 N	280 48	Mar 24	4.2 E	....	......
21CIV	22 53 N	291 08	Mar 16	3.3 W	....	......	43CIV	10 41 N	280 19	Mar 24	....	38.1 N	.321
22CIV	22 36 N	292 33	Mar 17	4.2 W	....	......							

Cruise IV, PACIFIC OCEAN, 1915.

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.	Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	*1915*	°	°	*c.g.s.*		° ′	° ′	*1915*	°	°	*c.g.s.*
44CIV	8 34 N	280 30	Apr 12	....	35.0 N	.321	81CIV	3 49 N	264 38	Apr 25	8.6 E	....	......
45CIV	8 21 N	280 28	Apr 12	4.7 E	....	......	82CIV	3 50 N	264 33	Apr 25	....	21.0 N	.338
46CIV	6 20 N	279 49	Apr 13	....	31.0 N	.326	83CIV	3 52 N	264 25	Apr 25	8.7 E	....	......
47CIV	6 16 N	279 48	Apr 13	5.3 E	....	......	84CIV	4 12 N	263 39	Apr 26	8.7 E	....	......
48CIV	5 50 N	279 47	Apr 14	5.6 E	....	......	85CIV	4 13 N	263 33	Apr 26	....	21.4 N	.340
49CIV	5 16 N	279 41	Apr 14	....	29.1 N	.325	86CIV	4 13 N	263 34	Apr 26	8.9 E	....	......
50CIV	5 07 N	279 39	Apr 14	5.4 E	....	......	87CIV	4 56 N	262 07	Apr 27	....	22.1 N	.340
51CIV[1]	4 18 N	279 34	Apr 15	5.7 E	....	......	88CIV	5 13 N	261 49	Apr 27	8.6 E	....	......
52CIV[1]	4 08 N	279 35	Apr 15	....	27.0 N	.326	89CIV	6 03 N	261 31	Apr 28	8.8 E	....	......
53CIV	3 36 N	279 13	Apr 15	6.0 E	....	......	90CIV	6 37 N	261 07	Apr 28	....	25.1 N	.342
54CIV	2 52 N	278 32	Apr 16	6.5 E	....	......	91CIV	7 47 N	260 38	Apr 29	8.7 E	....	......
55CIV	2 28 N	277 59	Apr 16	....	23.8 N	.326	92CIV	8 18 N	260 39	Apr 29	....	27.7 N	.342
56CIV	2 18 N	277 47	Apr 16	6.7 E	....	......	93CIV	8 20 N	260 41	Apr 29	9.0 E	....	......
57CIV	2 08 N	277 00	Apr 17	6.8 E	....	......	94CIV	8 22 N	260 11	Apr 30	8.8 E	....	......
58CIV	2 09 N	275 57	Apr 17	....	22.5 N	.328	95CIV	8 29 N	259 33	Apr 30	....	27.8 N	.341
59CIV	2 10 N	275 35	Apr 17	7.2 E	....	......	96CIV	8 30 N	259 26	Apr 30	8.6 E	....	......
60CIV	2 19 N	274 19	Apr 18	7.5 E	....	......	97CIV	8 29 N	258 26	May 1	9.1 E	....	......
61CIV	2 25 N	273 32	Apr 18	....	21.6 N	.332	98CIV	8 44 N	257 38	May 1	....	27.6 N	.340
62CIV	2 22 N	273 15	Apr 18	7.6 E	....	......	99CIV	8 51 N	257 18	May 1	8.8 E	....	......
63CIV	2 11 N	272 20	Apr 19	8.0 E	....	......	100CIV	9 37 N	255 58	May 2	9.1 E	....	......
64CIV	2 07 N	271 37	Apr 19	....	20.5 N	.334	101CIV	9 53 N	255 05	May 2	....	28.8 N	.342
65CIV	2 04 N	271 23	Apr 19	7.9 E	....	......	102CIV	9 55 N	254 55	May 2	8.9 E	....	......
66CIV	2 01 N	270 08	Apr 20	8.5 E	....	......	103CIV	10 12 N	254 02	May 3	8.9 E	....	......
67CIV	2 15 N	269 14	Apr 20	....	19.6 N	.335	104CIV	10 19 N	253 19	May 3	....	29.4 N	.341
68CIV	2 20 N	268 59	Apr 20	8.4 E	....	......	105CIV	10 17 N	252 53	May 3	8.9 E	....	......
69CIV	2 53 N	267 48	Apr 21	8.5 E	....	......	106CIV	10 14 N	250 54	May 4	9.3 E	....	......
70CIV	2 59 N	266 55	Apr 21	....	19.6 N	.340	107CIV	10 34 N	249 44	May 4	....	28.9 N	.341
71CIV	3 02 N	266 38	Apr 21	8.6 E	....	......	108CIV	10 39 N	249 31	May 4	9.0 E	....	......
72CIV	3 21 N	264 53	Apr 22	8.6 E	....	......	109CIV	10 58 N	248 11	May 5	9.1 E	....	......
73CIV	3 57 N	264 23	Apr 22	....	21.1 N	.339	110CIV	11 13 N	247 16	May 5	....	29.7 N	.340
74CIV	4 09 N	264 19	Apr 22	9.0 E	....	......	111CIV	11 18 N	246 56	May 5	9.2 E	....	......
75CIV	4 41 N	264 00	Apr 23	8.6 E	....	......	112CIV	11 46 N	245 12	May 6	9.1 E	....	......
76CIV	5 04 N	263 47	Apr 23	....	23.1 N	.340	113CIV	11 58 N	244 31	May 6	....	30.3 N	.339
77CIV	5 12 N	263 43	Apr 23	8.6 E	....	......	114CIV	12 35 N	242 29	May 7	9.3 E	....	......
78CIV	4 35 N	263 56	Apr 24	8.7 E	....	......	115CIV	12 51 N	241 34	May 7	....	31.2 N	.335
79CIV	4 26 N	263 53	Apr 24	....	21.8 N	.340	116CIV	12 56 N	241 17	May 7	9.4 E	....	......
80CIV	4 22 N	263 54	Apr 24	8.7 E	....	......	117CIV	13 29 N	239 42	May 8	9.5 E	....	......

[1]Swinging ship. [2]Mean of four positions. [3]Station 5CIV rejected.

CRUISE IV, PACIFIC OCEAN, 1915—*Continued.*

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	1915	°	°	c.g.s.
118CIV	13 42 N	238 55	May 8	....	32.4 N	.333
119CIV	13 47 N	238 34	May 8	9.8 E	....	.....
120CIV	14 20 N	236 46	May 9	9.8 E	....	.....
121CIV	14 48 N	235 36	May 9	....	33.7 N	.329
122CIV	14 57 N	235 11	May 9	9.8 E	....	.....
123CIV	15 37 N	233 10	May 10	9.9 E	....	.....
124CIV	15 56 N	232 28	May 10	....	35.0 N	.324
125CIV	16 00 N	232 17	May 10	9.9 E	....	.....
126CIV	16 40 N	230 27	May 11	10.5 E	....	.....
127CIV	16 53 N	229 48	May 11	....	36.0 N	.321
128CIV	17 01 N	229 03	May 11	10.1 E	....	.....
129CIV	17 31 N	226 46	May 12	....	36.9 N	.317
130CIV	17 32 N	226 34	May 12	10.4 E	....	.....
131CIV	17 34 N	226 18	May 12	10.5 E	....	.....
132CIV	18 01 N	224 32	May 13	10.6 E	....	.....
133CIV	18 19 N	223 46	May 13	....	37.5 N	.314
134CIV	18 29 N	223 30	May 13	10.5 E	....	.....
135CIV	18 51 N	221 53	May 14	10.9 E	....	.....
136CIV	19 13 N	220 56	May 14	....	38.3 N	.310
137CIV	19 26 N	220 41	May 14	10.9 E	....	.....
138CIV	19 39 N	218 46	May 15	11.2 E	....	.....
139CIV	19 48 N	217 46	May 15	....	38.9 N	.304
140CIV	19 51 N	217 23	May 15	10.5 E	....	.....
141CIV	19 52 N	216 10	May 16	11.0 E	....	.....
142CIV	19 57 N	215 13	May 16	....	38.8 N	.303
143CIV	20 01 N	214 48	May 16	10.6 E	....	.....
144CIV	20 19 N	213 11	May 17	10.9 E	....	.....
145CIV	20 38 N	211 56	May 17	....	39.1 N	.300
146CIV	20 40 N	211 39	May 17	11.1 E	....	.....
147CIV	20 49 N	210 02	May 18	10.8 E	....	.....
148CIV	20 54 N	209 05	May 18	....	38.9 N	.297
149CIV	20 56 N	208 48	May 18	10.2 E	....	.....
150CIV	21 04 N	206 51	May 19	10.7 E	....	.....
151CIV	21 08 N	206 08	May 19	....	39.1 N	.294
152CIV	21 11 N	205 51	May 19	10.6 E	....	.....
153CIV	21 27 N	204 11	May 20	10.6 E	....	.....
154CIV	21 24 N	203 07	May 20	....	39.6 N	.291
155CIV	21 21 N	202 50	May 20	11.0 E	....	.....
156CIV	21 14 N	202 20	May 21	10.8 E	....	.....
157CIV[1]	21 15 N	202 02	Jun 29 – Jul 3	10.7 E	38.9 N	.292
158CIV	22 10 N	201 22	Jul 4	10.6 E	....	.....
159CIV	23 08 N	201 10	Jul 4	....	40.7 N	.288
160CIV	23 27 N	201 00	Jul 4	11.0 E	....	.....
161CIV	25 01 N	200 14	Jul 5	11.5 E	....	.....
162CIV	26 05 N	199 34	Jul 5	....	44.3 N	.279
163CIV	26 22 N	199 26	Jul 5	11.6 E	....	.....
164CIV[2]	27 32 N	198 58	Jul 6	12.0 E	....	.....
165CIV	28 17 N	198 53	Jul 6	....	46.3 N	.275
166CIV	28 30 N	198 52	Jul 6	12.2 E	....	.....
167CIV	29 22 N	198 46	Jul 7	12.7 E	....	.....
168CIV	30 02 N	198 42	Jul 7	....	48.1 N	.269
169CIV	30 14 N	198 41	Jul 7	12.8 E	....	.....
170CIV	30 52 N	198 39	Jul 8	12.8 E	....	.....
171CIV	31 33 N	198 34	Jul 8	....	49.5 N	.267
172CIV	31 50 N	198 33	Jul 8	12.9 E	....	.....
173CIV	32 51 N	198 34	Jul 9	13.3 E	....	.....
174CIV	34 10 N	198 36	Jul 9	....	51.9 N	.262
175CIV	36 26 N	198 47	Jul 10	14.5 E	....	.....
176CIV	36 29 N	198 48	Jul 10	....	54.1 N	.254
177CIV[3]	37 17 N	196 50	Jul 11	14.1 E	....	.....
178CIV	37 41 N	195 44	Jul 11	....	54.8 N	.255
179CIV	37 50 N	195 27	Jul 11	13.8 E	....	.....
180CIV	38 40 N	193 55	Jul 12	14.2 E	....	.....
181CIV	39 12 N	192 58	Jul 12	....	55.1 N	.250
182CIV	39 30 N	192 32	Jul 12	13.5 E	....	.....
183CIV	40 12 N	191 02	Jul 13	12.9 E	....	.....
184CIV	40 27 N	190 25	Jul 13	....	55.8 N	.247
185CIV	40 58 N	189 29	Jul 14	....	55.8 N	248

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	1915	°	°	c.g.s.
186CIV	41 03 N	189 29	Jul 14	12.4 E	....	.....
187CIV	41 18 N	189 32	Jul 14	12.7 E	....	.....
188CIV	42 12 N	189 40	Jul 15	12.6 E	....	.....
189CIV	42 33 N	189 41	Jul 15	....	57.2 N	.244
190CIV	42 33 N	189 40	Jul 15	12.9 E	....	.....
191CIV	43 35 N	189 43	Jul 16	....	58.1 N	.241
192CIV	43 52 N	189 46	Jul 16	12.8 E	....	.....
193CIV	44 00 N	189 48	Jul 16	12.8 E	....	.....
194CIV	45 06 N	190 01	Jul 17	13.2 E	....	.....
195CIV	46 32 N	190 14	Jul 17	....	60.4 N	.233
196CIV	49 03 N	190 30	Jul 18	13.8 E	....	.....
197CIV	49 40 N	190 25	Jul 18	....	63.1 N	.223
198CIV	50 00 N	190 24	Jul 18	14.0 E	....	.....
199CIV	50 10 N	190 24	Jul 18	14.0 E	....	.....
200CIV	52 21 N	189 54	Jul 19	14.1 E	....	.....
201CIV	52 40 N	190 39	Jul 19	....	65.4 N	.212
202CIV[3]	53 00 N	190 49	Jul 19	14.4 E	....	.....
203CIV[4]	53 54 N	193 28	Jul 23	16.5 E	....	.....
204CIV	54 18 N	193 22	Aug 5	....	67.6 N	.200
205CIV	56 37 N	192 27	Aug 6	....	68.3 N	.196
206CIV	57 24 N	193 05	Aug 7	....	69.4 N	.189
207CIV	57 37 N	193 02	Aug 7	16.4 E	....	.....
208CIV	58 07 N	193 12	Aug 8	16.4 E	....	.....
209CIV	58 00 N	192 04	Aug 8	....	69.7 N	.184
210CIV	57 55 N	191 38	Aug 8	15.1 E	....	.....
211CIV	57 53 N	191 26	Aug 8	14.7 E	....	.....
212CIV	57 40 N	190 59	Aug 9	15.4 E	....	.....
213CIV	58 12 N	189 46	Aug 9	....	70.0 N	.186
214CIV	59 05 N	188 31	Aug 10	15.4 E	....	.....
215CIV	59 02 N	187 36	Aug 10	....	69.8 N	.184
216CIV[3]	59 01 N	187 36	Aug 10	13.5 E	....	.....
217CIV	59 26 N	187 20	Aug 11	12.5 E	....	.....
218CIV	59 33 N	186 33	Aug 11	....	70.2 N	.182
219CIV	59 29 N	186 00	Aug 11	11.4 E	....	.....
220CIV	59 01 N	183 43	Aug 12	11.6 E	....	.....
221CIV	58 42 N	182 36	Aug 12	....	69.5 N	.188
222CIV	58 36 N	182 21	Aug 12	9.4 E	....	.....
223CIV	58 30 N	182 02	Aug 12	10.2 E	....	.....
224CIV[5]	57 49 N	180 18	Aug 13	9.2 E	....	.....
225CIV	57 02 N	178 49	Aug 13	....	67.9 N	.198
226CIV	56 57 N	178 36	Aug 13	7.6 E	....	.....
227CIV[1]	56 44 N	177 05	Aug 15	6.7 E	....	.....
228CIV[1]	56 37 N	176 59	Aug 15	....	67.3 N	.202
229CIV[1]	56 28 N	177 02	Aug 15	6.9 E	....	.....
230CIV	55 49 N	175 37	Aug 16	6.1 E	....	.....
231CIV	55 36 N	175 13	Aug 16	....	66.3 N	.207
232CIV	55 28 N	174 01	Aug 16	4.8 E	....	.....
233CIV	54 35 N	173 21	Aug 17	4.7 E	....	.....
234CIV	53 46 N	172 05	Aug 17	....	64.7 N	.217
235CIV	53 35 N	171 55	Aug 17	3.7 E	....	.....
236CIV	52 22 N	170 18	Aug 18	3.3 E	....	.....
237CIV	51 35 N	169 39	Aug 18	....	63.1 N	.225
238CIV[3]	51 13 N	168 38	Aug 19	2.2 E	....	.....
239CIV	51 14 N	168 28	Aug 19	....	62.2 N	.231
240CIV	49 46 N	168 16	Aug 20	1.9 E	....	.....
241CIV	49 12 N	168 21	Aug 20	....	60.5 N	.237
242CIV	48 14 N	168 22	Aug 21	1.7 E	....	.....
243CIV	48 13 N	168 17	Aug 21	....	60.4 N	.238
244CIV	48 04 N	167 43	Aug 21	2.1 E	....	.....
245CIV	47 27 N	166 45	Aug 22	1.7 E	....	.....
246CIV	46 46 N	166 03	Aug 22	....	58.4 N	.246
247CIV	46 39 N	165 52	Aug 22	1.2 E	....	.....
248CIV	45 48 N	164 43	Aug 23	0.8 E	....	.....
249CIV	45 20 N	164 07	Aug 23	....	57.4 N	.248
250CIV	45 20 N	164 00	Aug 23	0.7 E	....	.....
251CIV[3]	45 00 N	163 18	Aug 24	0.7 E	....	.....
252CIV	44 45 N	162 54	Aug 24	....	56.7 N	.252
253CIV	44 38 N	162 48	Aug 24	0.3 E	....	.....
254CIV	44 32 N	162 49	Aug 25	0.2 E	....	.....

[1] Swinging ship.
[2] Mean of three positions.
[3] Mean of two positions.
[4] Taken at anchor, Dutch Harbor.
[5] Crossed 180th meridian, hence, date August 14 omitted.

CRUISE IV, PACIFIC OCEAN, 1915—*Continued.*

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.	Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	1915	°	°	c. g. s.		° ′	° ′	1915	°	°	c. g. s.
255CIV	44 29 N	163 12	Aug 25		56.1 N	.257	324CIV	12 29 N	165 01	Sep 18	7.2 E		
256CIV	44 21 N	163 10	Aug 25	0.4 E			325CIV*	12 02 N	164 36	Sep 18		13.0 N	.333
257CIV	41 19 N	163 30	Aug 26		53.3 N	.262	326CIV*	11 57 N	164 32	Sep 18	6.1 E		
258CIV	40 33 N	163 35	Aug 26	1.2 E			327CIV	11 31 N	164 23	Sep 19	7.1 E		
259CIV	39 31 N	163 49	Aug 27	1.8 E			328CIV	11 14 N	164 14	Sep 19		13.1 N	.332
260CIV	38 30 N	164 09	Aug 27		50.6 N	.269	329CIV	11 13 N	164 12	Sep 19	6.8 E		
261CIV	38 15 N	164 13	Aug 27	2.2 E			330CIV	10 40 N	164 06	Sep 20	7.0 E		
262CIV	37 50 N	164 16	Aug 27	2.1 E			331CIV	10 00 N	164 00	Sep 20		10.7 N	.336
263CIV[1]	36 51 N	164 28	Aug 28	2.4 E			332CIV	9 46 N	163 56	Sep 20	6.8 E		
264CIV	36 23 N	165 09	Aug 28		48.2 N	.275	333CIV	9 17 N	163 41	Sep 21	7.0 E		
265CIV	36 08 N	165 25	Aug 28	3.1 E			334CIV	8 47 N	163 33	Sep 21		8.5 N	.340
266CIV	35 13 N	166 42	Aug 29	4.0 E			335CIV	8 40 N	163 29	Sep 21	6.8 E		
267CIV	34 55 N	167 47	Aug 29		46.9 N	.275	336CIV	8 06 N	163 32	Sep 22	7.1 E		
268CIV	34 54 N	168 07	Aug 29	4.2 E			337CIV	8 04 N	163 39	Sep 22		7.2 N	.341
269CIV[1]	34 26 N	169 44	Aug 30	5.5 E			338CIV	7 45 N	163 47	Sep 22	6.8 E		
270CIV	33 33 N	170 19	Aug 30		45.8 N	.274	339CIV	7 19 N	164 05	Sep 23	7.2 E		
271CIV[1]	33 22 N	170 30	Aug 30	5.6 E			340CIV	6 52 N	164 16	Sep 23		5.2 N	.343
272CIV	32 16 N	170 48	Aug 31	6.1 E			341CIV	6 42 N	164 20	Sep 23	7.2 E		
273CIV	31 34 N	171 04	Aug 31		44.1 N	.277	342CIV	5 56 N	164 38	Sep 24	7.6 E		
274CIV	31 13 N	171 10	Aug 31	6.3 E			343CIV	5 09 N	164 38	Sep 24		1.7 N	.348
275CIV	30 28 N	171 18	Sep 1	6.8 E			344CIV	4 56 N	164 33	Sep 24	7.6 E		
276CIV	30 03 N	171 06	Sep 1		42.3 N	.281	345CIV	4 23 N	164 14	Sep 25	7.4 E		
277CIV	30 02 N	171 06	Sep 1	6.9 E			346CIV	4 17 N	163 58	Sep 25		0.1 S	.350
278CIV	29 18 N	170 42	Sep 2	6.6 E			347CIV	4 16 N	163 54	Sep 25	7.2 E		
279CIV	29 06 N	170 39	Sep 2		40.9 N	.283	348CIV	4 04 N	163 50	Sep 26	7.4 E		
280CIV	28 57 N	170 35	Sep 2	6.4 E			349CIV	3 52 N	163 58	Sep 26		0.8 S	.351
281CIV	28 39 N	170 16	Sep 3	6.8 E			350CIV	3 40 N	163 56	Sep 27	7.3 E		
282CIV	28 10 N	170 05	Sep 3		40.0 N	.286	351CIV	3 40 N	163 50	Sep 27		1.0 S	.353
283CIV	27 59 N	170 04	Sep 3	6.4 E			352CIV	3 36 N	163 45	Sep 27	7.3 E		
284CIV	27 41 N	170 01	Sep 3	6.6 E			353CIV	3 25 N	163 02	Sep 28	7.3 E		
285CIV	27 17 N	169 49	Sep 4	6.6 E			354CIV	3 16 N	162 51	Sep 28		2.4 S	.354
286CIV	26 44 N	169 23	Sep 4	6.4 E			355CIV	3 11 N	162 42	Sep 28	7.2 E		
287CIV	25 50 N	168 43	Sep 4		36.7 N	.291	356CIV	3 01 N	162 05	Sep 29	7.2 E		
288CIV	25 37 N	168 35	Sep 4	6.4 E			357CIV	2 59 N	162 06	Sep 29		3.2 S	.354
289CIV	23 19 N	167 30	Sep 5	6.5 E			358CIV	2 56 N	162 05	Sep 29	7.1 E		
290CIV	22 09 N	167 06	Sep 5		32.0 N	.301	359CIV	2 28 N	161 53	Sep 30	7.1 E		
291CIV	21 56 N	167 02	Sep 5	6.3 E			360CIV	2 20 N	161 36	Sep 30		4.8 S	.357
292CIV	20 17 N	167 10	Sep 6		29.4 N	.304	361CIV	2 20 N	161 32	Sep 30	6.9 E		
293CIV	21 27 N	169 07	Sep 7	6.8 E			362CIV	1 55 N	160 34	Oct 1	6.9 E		
294CIV	21 30 N	169 19	Sep 7		31.2 N	.300	363CIV	2 00 N	160 41	Oct 1		5.7 S	.357
295CIV	21 31 N	169 22	Sep 7	7.0 E			364CIV	2 05 N	160 50	Oct 1	6.8 E		
296CIV	21 21 N	169 47	Sep 8	7.4 E			365CIV	1 01 N	160 07	Oct 2	6.8 E		
297CIV	21 15 N	169 19	Sep 8		30.6 N	.303	366CIV	0 10 N	159 51	Oct 2		9.5 S	.362
298CIV	21 02 N	168 32	Sep 9	7.1 E			367CIV	0 04 S	159 50	Oct 2	6.8 E		
299CIV	21 01 N	168 30	Sep 9		30.4 N	.303	368CIV	1 31 S	159 43	Oct 3	6.9 E		
300CIV	20 40 N	168 13	Sep 10	7.0 E			369CIV	2 25 S	160 03	Oct 3		14.6 S	.365
301CIV	20 39 N	168 07	Sep 10		29.8 N	.304	370CIV	2 40 S	160 11	Oct 3	7.3 E		
302CIV	20 37 N	168 04	Sep 10	6.9 E			371CIV	3 46 S	160 54	Oct 4	7.4 E		
303CIV	20 18 N	167 41	Sep 11	7.0 E			372CIV	4 24 S	161 16	Oct 4		18.0 S	.366
304CIV	19 50 N	167 06	Sep 11		28.2 N	.307	373CIV	4 29 S	161 21	Oct 4	7.4 E		
305CIV	19 44 N	166 55	Sep 11	6.6 E			374CIV	4 58 S	161 48	Oct 5	7.6 E		
306CIV	19 14 N	166 28	Sep 12	7.0 E			375CIV	5 12 S	162 20	Oct 5		19.5 S	.367
307CIV	18 45 N	166 11	Sep 12		26.2 N	.312	376CIV	5 49 S	163 29	Oct 6		20.4 S	.368
308CIV	18 36 N	166 06	Sep 12	6.6 E			377CIV	5 56 S	163 36	Oct 6	8.2 E		
309CIV	17 32 N	165 33	Sep 13	6.6 E			378CIV	6 30 S	164 02	Oct 7		21.2 S	.367
310CIV	16 43 N	165 21	Sep 13		22.6 N	.317	379CIV	6 31 S	164 03	Oct 7	8.0 E		
311CIV	16 34 N	165 21	Sep 13	7.1 E			380CIV	7 20 S	163 25	Oct 8	8.0 E		
312CIV	15 29 N	165 17	Sep 14	6.7 E			381CIV	7 55 S	163 12	Oct 8		24.7 S	.368
313CIV	15 06 N	165 12	Sep 14		20.4 N	.321	382CIV	8 08 S	163 09	Oct 8	8.2 E		
314CIV	14 33 N	165 11	Sep 14	6.6 E			383CIV	9 09 S	162 50	Oct 9	8.5 E		
315CIV	14 13 N	164 50	Sep 15	6.9 E			384CIV	9 36 S	162 42	Oct 9		27.5 S	.366
316CIV	14 17 N	164 55	Sep 15		18.8 N	.323	385CIV	9 44 S	162 36	Oct 9	8.1 E		
317CIV	14 16 N	165 01	Sep 15	6.7 E			386CIV	10 24 S	162 44	Oct 10		29.0 S	.365
318CIV	14 00 N	165 33	Sep 16	6.9 E			387CIV	11 20 S	162 31	Oct 11	8.3 E		
319CIV	13 48 N	166 11	Sep 16		18.4 N	.323	388CIV	11 56 S	161 48	Oct 11		32.2 S	.362
320CIV	13 47 N	166 16	Sep 16	7.2 E			389CIV	12 12 S	161 28	Oct 11	8.2 E		
321CIV	13 46 N	166 24	Sep 17	7.1 E			390CIV	12 24 S	161 22	Oct 12	8.2 E		
322CIV	13 27 N	166 05	Sep 17		17.9 N	.324	391CIV	12 54 S	160 45	Oct 12		34.0 S	.360
323CIV	13 21 N	165 58	Sep 17	7.0 E			392CIV	13 01 S	160 42	Oct 12	8.2 E		

*Local disturbance; near Marshall Islands. [1]Mean of two positions.

CRUISE IV, PACIFIC OCEAN, 1915—*Continued.*

Station	Lat.		Long. E. of Gr.		Date		Declination	Inclination	Hor. Int	Station	Lat.		Long. E. of Gr.		Date		Declination	Inclination	Hor. Int.
	°	′	°	′	*1915*		°	°	*c. g. s.*		°	′	°	′	*1915*		°	°	*c. g. s.*
393CIV	13	52 S	159	58	Oct	13	8.2 E	....	......	422CIV	33	30 S	157	25	Oct	23	....	62.1 S	.267
394CIV	14	02 S	159	34	Oct	13	....	36.2 S	.358	423CIV[2]	33	48 S	157	34	Oct	23	11.1 E	....	......
395CIV	14	14 S	159	19	Oct	13	8.0 E	....	......	424CIV[2]	35	32 S	158	14	Oct	24	11.5 E	....	......
396CIV	15	33 S	158	41	Oct	14	7.9 E	....	......	425CIV	35	45 S	158	28	Oct	24	....	64.3 S	.254
397CIV	16	41 S	158	16	Oct	14	....	40.8 S	.352	426CIV	35	54 S	158	48	Oct	24	11.7 E	....	......
398CIV	17	02 S	158	08	Oct	14	8.1 E	....	......	427CIV	36	22 S	159	51	Oct	25	12.9 E	....	......
399CIV	18	37 S	157	46	Oct	15	8.4 E	....	......	428CIV	36	19 S	159	50	Oct	25	....	64.4 S	.253
400CIV*	19	52 S	157	31	Oct	15	....	45.4 S	.340	429CIV	37	00 S	160	40	Oct	26	13.0 E	....	......
401CIV	20	16 S	157	24	Oct	15	8.3 E	....	......	430CIV	37	20 S	161	23	Oct	26	....	64.9 S	.247
402CIV	21	34 S	157	22	Oct	16	9.0 E	....	......	431CIV	37	27 S	161	27	Oct	26	13.0 E	....	......
403CIV	21	44 S	157	12	Oct	16	....	48.7 S	.328	432CIV	38	12 S	161	47	Oct	27	13.3 E	....	......
404CIV	21	50 S	157	05	Oct	16	8.9 E	....	......	433CIV	38	35 S	161	51	Oct	27	....	66.0 S	.241
405CIV	22	07 S	156	51	Oct	17	9.0 E	....	......	434CIV	38	41 S	161	52	Oct	27	13.2 E	....	......
406CIV	22	20 S	156	52	Oct	17	....	49.4 S	.327	435CIV	39	14 S	161	57	Oct	28	13.5 E	....	......
407CIV	23	10 S	157	00	Oct	18	8.7 E	....	......	436CIV	39	21 S	162	04	Oct	28	....	66.6 S	.237
408CIV	23	40 S	157	00	Oct	18	....	51.1 S	.321	437CIV	39	35 S	162	10	Oct	28	14.0 E	....	......
409CIV	23	43 S	157	00	Oct	18	9.0 E	....	......	438CIV	41	57 S	162	26	Oct	29	14.7 E	....	......
410CIV	23	55 S	156	50	Oct	19	9.0 E	....	......	439CIV	42	10 S	162	38	Oct	29	....	68.8 S	.221
411CIV	24	36 S	156	13	Oct	19	....	52.5 S	.315	440CIV[2]	42	31 S	162	42	Oct	29	15.0 E	....	......
412CIV	25	43 S	155	33	Oct	20	9.1 E	....	......	441CIV	43	58 S	163	29	Oct	30	15.7 E	....	......
413CIV	26	23 S	155	05	Oct	20	....	54.8 S	.307	442CIV	45	13 S	164	30	Oct	30	....	70.8 S	.204
414CIV[1]	26	38 S	154	57	Oct	20	8.7 E	....	......	443CIV[2]	45	36 S	164	53	Oct	30	16.4 E	....	......
415CIV	27	34 S	154	32	Oct	21	9.6 E	....	......	444CIV	46	31 S	167	20	Oct	31	16.8 E	....	......
416CIV	28	17 S	154	26	Oct	21	....	57.3 S	.294	445CIV†	46	41 S	168	13	Oct	31	....	71.4 S	.200
417CIV	28	35 S	154	30	Oct	21	9.4 E	....	......	446CIV	46	10 S	170	26	Nov	1	....	70.5 S	.206
418CIV	29	43 S	155	12	Oct	22	9.5 E	....	......	447CIV	45	14 S	172	00	Nov	2	17.7 E	....	......
419CIV	30	29 S	155	41	Oct	22	....	59.4 S	.285	448CIV	44	27 S	172	44	Nov	2	....	68.7 S	.219
420CIV	30	48 S	155	54	Oct	22	10.0 E	....	......	449CIV	44	16 S	172	50	Nov	2	17.2 E	....	......
421CIV	32	19 S	156	59	Oct	23	10.6 E	....	......	450CIV	43	42 S	173	09	Nov	3	17.1 E	....	......

CRUISE IV, SOUTHERN OCEANS, 1915–1916.

Station	Lat.		Long. E. of Gr.		Date		Declination	Inclination	Hor. Int	Station	Lat.		Long. E. of Gr.		Date		Declination	Inclination	Hor. Int.
	°	′	°	′	*1915*		°	°	*c. g. s.*		°	′	°	′	*1915*		°	°	*c. g. s.*
451CIV	43	47 S	173	20	Dec	6	17.1 E	....	......	487CIV	60	16 S	208	42	Dec	18	29.5 E	....	......
452CIV[2]	46	04 S	174	39	Dec	7	17.9 E	....	......	488CIV	60	10 S	209	28	Dec	18	....	74.8 S	.169
453CIV	46	27 S	174	51	Dec	7	....	70.0 S	.208	489CIV	60	18 S	212	42	Dec	19	29.3 E	....	......
454CIV	47	37 S	176	16	Dec	8	18.3 E	....	......	490CIV	60	20 S	214	56	Dec	19	....	74.2 S	.176
455CIV	48	10 S	176	39	Dec	8	....	70.6 S	.205	491CIV	60	20 S	215	31	Dec	19	30.7 E	....	......
456CIV	49	03 S	178	20	Dec	9	18.5 E	....	......	492CIV	60	26 S	218	49	Dec	20	30.6 E	....	......
457CIV	49	18 S	179	01	Dec	9	....	71.2 S	.199	493CIV	60	32 S	221	04	Dec	20	....	73.2 S	.183
458CIV	49	23 S	179	13	Dec	9	20.4 E	....	......	494CIV	60	32 S	221	08	Dec	20	30.9 E	....	......
459CIV[3]	49	56 S	180	47	Dec	9	20.4 E	....	......	495CIV	60	10 S	227	27	Dec	21	....	72.2 S	.192
460CIV	50	20 S	182	09	Dec	9	....	71.4 S	.198	496CIV	60	09 S	227	32	Dec	21	30.4 E	....	......
461CIV	50	28 S	182	26	Dec	9	21.5 E	....	......	497CIV	59	46 S	230	32	Dec	22	30.9 E	....	......
462CIV	50	34 S	182	43	Dec	9	20.9 E	....	......	498CIV	59	40 S	231	11	Dec	22	30.8 E	....	......
463CIV	51	27 S	184	10	Dec	10	....	72.1 S	.191	499CIV	59	39 S	232	30	Dec	22	....	71.0 S	.201
464CIV	51	29 S	184	13	Dec	10	21.3 E	....	......	500CIV	59	38 S	232	44	Dec	22	32.0 E	....	......
465CIV	53	03 S	186	18	Dec	11	22.4 E	....	......	501CIV	60	32 S	235	56	Dec	23	32.7 E	....	......
466CIV	53	28 S	187	10	Dec	11	....	72.9 S	.184	502CIV	60	33 S	236	14	Dec	23	....	70.5 S	.203
467CIV	53	34 S	187	17	Dec	11	21.5 E	....	......	503CIV	60	06 S	235	39	Dec	24	32.4 E	....	......
468CIV	53	51 S	187	44	Dec	11	22.0 E	....	......	504CIV	59	41 S	236	28	Dec	24	....	70.0 S	.209
469CIV	54	18 S	188	18	Dec	12	22.1 E	....	......	505CIV	59	37 S	236	34	Dec	24	31.6 E	....	......
470CIV	53	45 S	189	23	Dec	12	....	73.1 S	.185	506CIV	59	14 S	241	34	Dec	25	31.7 E	....	......
471CIV	53	44 S	189	47	Dec	12	22.3 E	....	......	507CIV	59	10 S	242	58	Dec	25	....	68.4 S	.219
472CIV	54	12 S	191	10	Dec	13	22.6 E	....	......	508CIV	59	10 S	244	09	Dec	25	31.7 E	....	......
473CIV	54	38 S	192	00	Dec	13	....	73.1 S	.185	509CIV	59	08 S	247	40	Dec	26	31.4 E	....	......
474CIV	54	46 S	192	14	Dec	13	23.3 E	....	......	510CIV	59	06 S	250	16	Dec	26	31.3 E	66.6 S	.233
475CIV	55	12 S	193	35	Dec	14	22.9 E	....	......	511CIV	59	05 S	251	16	Dec	26	31.6 E	....	......
476CIV	55	28 S	195	36	Dec	14	....	73.2 S	.184	512CIV	59	07 S	254	23	Dec	27	31.9 E	....	......
477CIV	55	29 S	195	38	Dec	14	23.5 E	....	......	513CIV	59	09 S	257	18	Dec	27	....	64.6 S	.240
478CIV	55	43 S	196	34	Dec	14	23.0 E	....	......	514CIV	59	07 S	257	36	Dec	27	31.0 E	....	......
479CIV	56	00 S	197	27	Dec	15	24.3 E	....	......	515CIV	59	03 S	258	34	Dec	27	30.7 E	....	......
480CIV	56	05 S	198	08	Dec	15	....	73.2 S	.182	516CIV	58	54 S	261	00	Dec	28	31.0 E	....	......
481CIV	56	08 S	198	24	Dec	15	24.0 E	....	......	517CIV	58	47 S	263	38	Dec	28	....	62.4 S	.250
482CIV	57	21 S	202	21	Dec	16	....	73.6 S	.179	518CIV	58	48 S	264	05	Dec	28	30.4 E	....	......
483CIV	57	36 S	202	46	Dec	16	25.7 E	....	......	519CIV	58	48 S	265	01	Dec	28	30.2 E	....	......
484CIV	58	25 S	204	22	Dec	17	26.8 E	....	......	520CIV	58	48 S	267	32	Dec	29	29.1 E	....	......
485CIV	59	15 S	205	58	Dec	17	....	74.5 S	.172	521CIV	58	48 S	268	57	Dec	29	....	60.7 S	.257
486CIV	59	26 S	206	18	Dec	17	27.0 E	....	......	522CIV	58	48 S	269	30	Dec	29	28.8 E	....	......

*Local disturbance; near Chesterfield reefs and islets. †Local disturbance; passing through Foveaux Strait.
[1]Low value of declination at station 414CIV probably caused by unfavorable observing conditions.
[2]Mean of two positions. [3]Crossed 180th meridian, hence, date Dec. 9 repeated.

CRUISE IV, SOUTHERN OCEANS, 1915–1916—*Continued.*

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	*1915*	°	°	*c. g. s.*
523CIV	58 48 S	270 14	Dec 30	28.6 E	....	......
524CIV	58 49 S	271 53	Dec 30	....	59.7 S	.259
525CIV	58 49 S	272 08	Dec 30	27.8 E	....	......
526CIV	58 50 S	273 02	Dec 31	27.9 E	....	......
527CIV	59 02 S	274 53	Dec 31	....	59.1 S	.260
528CIV	59 08 S	275 37	Dec 31	26.8 E	....	......
			1916			
529CIV	59 12 S	277 39	Jan 1	25.8 E	....	......
530CIV	59 22 S	280 39	Jan 1	24.7 E	....	......
531CIV	59 25 S	280 52	Jan 1	....	58.2 S	.261
532CIV	59 58 S	284 31	Jan 2	22.7 E	....	......
533CIV	60 08 S	286 12	Jan 2	....	57.1 S	.262
534CIV	60 08 S	286 20	Jan 2	22.4 E	....	......
535CIV	59 56 S	289 42	Jan 3	20.4 E	....	......
536CIV	59 41 S	291 40	Jan 3	18.7 E	55.6 S	.264
537CIV	59 41 S	292 39	Jan 3	19.1 E	....	......
538CIV	59 53 S	294 05	Jan 4	17.8 E	....	......
539CIV	60 00 S	294 42	Jan 4	....	55.2 S	.263
540CIV	59 33 S	295 59	Jan 5	16.5 E	....	......
541CIV	59 12 S	297 54	Jan 5	15.1 E	53.9 S	.264
542CIV	59 04 S	298 51	Jan 5	14.2 E	....	......
543CIV	58 47 S	300 42	Jan 6	13.8 E	....	......
544CIV	58 41 S	303 10	Jan 6	....	52.9 S	.262
545CIV	58 00 S	306 53	Jan 7	8.8 E	....	......
546CIV	57 35 S	308 17	Jan 7	....	51.4 S	.258
547CIV	57 26 S	308 58	Jan 7	7.4 E	....	......
548CIV	56 21 S	313 05	Jan 8	....	50.0 S	.254
549CIV[1]	56 20 S	313 06	Jan 8	3.9 E	....	......
550CIV	55 35 S	315 18	Jan 9	2.4 E	....	......
551CIV	55 28 S	315 41	Jan 9	....	49.6 S	.250
552CIV	54 18 S	319 17	Jan 10	1.4 W	....	......
553CIV	54 16 S	319 24	Jan 10	....	48.6 S	.246
554CIV	54 09 S	321 37	Jan 11	3.4 W	....	......
555CIV	53 57 S	321 28	Jan 11	....	48.9 S	.242
556CIV	53 54 S	321 46	Jan 11	3.1 W	....	......
557CIV	53 54 S	322 06	Jan 11	3.6 W	....	......
558CIV[2]	54 16 S	323 38	Jan 12	4.7 W	....	......
559CIV	54 14 S	325 27	Jan 15	5.7 W	....	......
560CIV	54 14 S	326 03	Jan 15	6.2 W	....	......
561CIV	54 17 S	327 51	Jan 15	....	50.1 S	.234
562CIV	54 19 S	328 38	Jan 15	7.7 W	....	......
563CIV	54 41 S	332 02	Jan 16	10.6 W	....	......
564CIV	54 42 S	332 10	Jan 16	....	51.1 S	.230
565CIV	54 34 S	334 48	Jan 17	12.1 W	....	......
566CIV	54 36 S	336 33	Jan 17	....	52.9 S	.220
567CIV	54 32 S	342 12	Jan 18	....	54.3 S	.214
568CIV	54 30 S	344 22	Jan 19	17.3 W	....	......
569CIV	54 29 S	345 19	Jan 19	17.5 W	....	......
570CIV	54 28 S	345 25	Jan 19	....	55.0 S	.211
571CIV	54 19 S	349 48	Jan 20	20.0 W	....	......
572CIV	54 18 S	350 28	Jan 20	20.4 W	....	......
573CIV	54 18 S	350 51	Jan 20	....	56.9 S	.203
574CIV	54 17 S	351 24	Jan 20	20.1 W	....	......
575CIV	54 16 S	357 17	Jan 21	....	59.0 S	.196
576CIV	53 53 S	358 10	Jan 21	22.8 W	....	......
577CIV	53 45 S	358 37	Jan 21	24.3 W	....	......
578CIV	53 41 S	0 39	Jan 22	25.2 W	....	......
579CIV	54 21 S	2 16	Jan 22	....	60.5 S	.188
580CIV	54 22 S	2 36	Jan 22	24.7 W	....	......
581CIV	53 48 S	4 19	Jan 23	25.3 W	....	......
582CIV	53 32 S	6 00	Jan 23	....	61.8 S	.181
583CIV	53 32 S	6 21	Jan 23	26.2 W	....	......
584CIV	53 39 S	9 22	Jan 24	27.1 W	....	......
585CIV	53 44 S	10 28	Jan 24	....	63.0 S	.176
586CIV	53 47 S	10 54	Jan 24	27.0 W	....	......
587CIV	54 03 S	14 35	Jan 25	28.5 W	....	......
588CIV	54 13 S	16 08	Jan 25	....	64.5 S	.171
589CIV	54 16 S	16 30	Jan 25	28.4 W	....	......
590CIV[1]	54 33 S	19 55	Jan 26	28.8 W	....	......

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	*1916*	°	°	*c. g. s.*
591CIV	54 28 S	22 00	Jan 26	....	65.8 S	.164
592CIV	54 27 S	22 16	Jan 26	29.2 W	....	......
593CIV	54 15 S	26 16	Jan 27	29.6 W	....	......
594CIV	54 17 S	26 57	Jan 27	....	66.6 S	.161
595CIV	53 56 S	29 43	Jan 28	29.5 W	....	......
596CIV	53 33 S	31 35	Jan 28	....	67.1 S	.160
597CIV	53 25 S	32 12	Jan 28	29.5 W	....	......
598CIV	52 55 S	34 55	Jan 29	30.6 W	....	......
599CIV	52 51 S	35 19	Jan 29	30.2 W	....	......
600CIV	52 34 S	37 26	Jan 29	....	67.5 S	.157
601CIV	52 46 S	38 40	Jan 30	31.3 W	....	......
602CIV	52 44 S	39 30	Jan 30	....	67.9 S	.156
603CIV	52 42 S	39 52	Jan 30	32.0 W	....	......
604CIV	51 53 S	42 33	Jan 31	31.5 W	....	......
605CIV	51 23 S	43 37	Jan 31	....	68.0 S	.156
606CIV	51 10 S	44 02	Jan 31	31.3 W	....	......
607CIV	50 06 S	46 23	Feb 1	30.8 W	....	......
608CIV	49 29 S	47 48	Feb 1	....	67.7 S	.158
609CIV	49 18 S	48 17	Feb 1	31.0 W	....	......
610CIV	48 36 S	50 00	Feb 2	30.9 W	....	......
611CIV	48 36 S	51 26	Feb 2	....	68.0 S	.158
612CIV	48 35 S	51 58	Feb 2	31.7 W	....	......
613CIV	48 35 S	52 13	Feb 2	31.8 W	....	......
614CIV	48 34 S	54 00	Feb 3	33.1 W	....	......
615CIV	48 34 S	55 43	Feb 3	....	67.6 S	.163
616CIV	48 34 S	56 08	Feb 3	33.5 W	....	......
617CIV	48 44 S	60 23	Feb 4	35.0 W	....	......
618CIV	48 44 S	60 30	Feb 4	....	68.0 S	.166
619CIV	48 48 S	60 59	Feb 4	35.1 W	....	......
620CIV	49 00 S	63 29	Feb 5	34.4 W	....	......
621CIV	49 03 S	64 06	Feb 5	....	68.2 S	.168
622CIV	49 05 S	64 35	Feb 5	36.1 W	....	......
623CIV	49 24 S	66 12	Feb 6	37.7 W	....	......
624CIV	49 39 S	67 56	Feb 6	....	68.7 S	.170
625CIV	50 09 S	68 01	Feb 6	38.5 W	....	......
626CIV	50 38 S	69 35	Feb 7	39.6 W	....	......
627CIV	51 14 S	71 30	Feb 7	....	69.3 S	.170
628CIV	51 26 S	72 10	Feb 7	40.6 W	....	......
629CIV	51 42 S	73 22	Feb 8	41.5 W	....	......
630CIV	52 19 S	75 36	Feb 8	43.1 W	70.5 S	.170
631CIV	52 28 S	76 29	Feb 8	41.7 W	....	......
632CIV	51 41 S	77 12	Feb 9	41.5 W	....	......
633CIV	50 47 S	78 14	Feb 9	....	70.7 S	.168
634CIV	50 28 S	78 38	Feb 9	42.3 W	....	......
635CIV	49 26 S	80 49	Feb 10	....	71.2 S	.168
636CIV	49 11 S	81 10	Feb 10	40.2 W	....	......
637CIV	49 06 S	81 16	Feb 10	41.9 W	....	......
638CIV	47 38 S	82 58	Feb 11	39.2 W	....	......
639CIV	46 52 S	83 59	Feb 11	....	70.9 S	.172
640CIV[1]	46 35 S	84 16	Feb 11	38.0 W	....	......
641CIV	44 39 S	85 58	Feb 12	35.9 W	....	......
642CIV	43 49 S	86 47	Feb 12	....	70.4 S	.178
643CIV	43 32 S	87 02	Feb 12	34.4 W	....	......
644CIV	41 47 S	88 12	Feb 13	30.8 W	....	......
645CIV	40 59 S	88 44	Feb 13	....	69.5 S	.185
646CIV	40 48 S	88 51	Feb 13	30.4 W	....	......
647CIV	40 33 S	88 58	Feb 13	29.7 W	....	......
648CIV	39 02 S	89 49	Feb 14	28.0 W	....	......
649CIV	37 58 S	90 43	Feb 14	....	68.7 S	.194
650CIV	37 45 S	90 53	Feb 14	25.6 W	....	......
651CIV	37 34 S	91 02	Feb 14	26.4 W	....	......
652CIV	35 58 S	92 32	Feb 15	22.9 W	....	......
653CIV	35 41 S	93 33	Feb 15	22.7 W	67.9 S	.201
654CIV	35 32 S	93 56	Feb 15	21.8 W	....	......
655CIV	34 55 S	95 20	Feb 16	20.5 W	....	......
656CIV	34 22 S	96 13	Feb 16	....	67.2 S	.210
657CIV	34 09 S	96 23	Feb 16	18.6 W	....	......
658CIV	34 54 S	95 36	Feb 17	20.6 W	....	......
659CIV	35 09 S	95 30	Feb 17	....	67.5 S	.207

[1]Mean of two positions. [2]Entrance to Cumberland Bay, South Georgia.

CRUISE IV, SOUTHERN OCEANS, 1915–1916—*Concluded.*

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	*1916*	°	°	*c. g. s.*
660CIV	36 11 S	95 23	Feb 18	21.9 W	68.2 S	.202
661CIV	36 10 S	96 58	Feb 19	21.0 W	....	......
662CIV	35 58 S	97 30	Feb 19	....	68.4 S	.203
663CIV	35 56 S	97 34	Feb 19	20.1 W	....	......
664CIV	36 02 S	97 36	Feb 19	19.7 W	....	......
665CIV	37 12 S	97 28	Feb 20	21.4 W	....	......
666CIV	37 44 S	97 33	Feb 20	....	69.3 S	.196
667CIV	38 02 S	97 34	Feb 20	22.2 W	....	......
668CIV	39 22 S	98 28	Feb 21	23.0 W	....	......
669CIV	39 57 S	99 24	Feb 21	....	70.9 S	.186
670CIV	40 04 S	99 35	Feb 21	23.7 W	....	......
671CIV	41 48 S	100 18	Feb 22	25.6 W	....	......
672CIV	42 43 S	100 31	Feb 22	....	72.3 S	.174
673CIV	43 07 S	100 36	Feb 22	26.2 W	....	......
674CIV	46 31 S	101 36	Feb 23	....	74.4 S	.159
675CIV	46 48 S	101 43	Feb 23	31.8 W	....	......
676CIV	47 39 S	101 58	Feb 24	32.6 W	....	......
677CIV	47 58 S	102 03	Feb 24	....	75.2 S	.153
678CIV	47 58 S	102 04	Feb 24	33.4 W	....	......
679CIV	47 55 S	102 56	Feb 25	33.0 W	....	......
680CIV	47 48 S	103 50	Feb 25	....	75.5 S	.153
681CIV	47 51 S	104 08	Feb 25	30.3 W	....	......
682CIV	49 13 S	104 25	Feb 26	33.7 W	....	......
683CIV	50 18 S	105 05	Feb 26	....	76.5 S	.141
684CIV	50 35 S	105 19	Feb 26	34.4 W	....	......
685CIV	52 04 S	106 16	Feb 27	36.5 W	....	......
686CIV	52 50 S	106 49	Feb 27	....	78.2 S	.129
687CIV	53 03 S	107 02	Feb 27	37.4 W	....	......
688CIV	54 13 S	107 29	Feb 28	40.4 W	....	......
689CIV	54 59 S	107 38	Feb 28	....	79.0 S	.122
690CIV	57 10 S	108 17	Feb 29	45.9 W	....	......
691CIV	57 17 S	108 36	Feb 29	....	80.0 S	.112
692CIV	57 31 S	108 44	Feb 29	45.4 W	....	......
693CIV	58 49 S	109 20	Mar 1	49.6 W	....	......
694CIV	58 59 S	109 36	Mar 1	49.7 W	....	......
695CIV	59 24 S	110 21	Mar 1	....	80.6 S	.105
696CIV	59 24 S	110 24	Mar 1	50.6 W	....	......
697CIV	59 17 S	110 51	Mar 1	50.5 W	....	......
698CIV	57 46 S	111 59	Mar 2	44.5 W	....	......
699CIV	56 22 S	112 32	Mar 2	....	80.3 S	.108
700CIV	56 18 S	112 33	Mar 2	41.8 W	....	......
701CIV	54 32 S	113 24	Mar 3	36.2 W	....	......
702CIV	53 26 S	113 50	Mar 3	....	79.5 S	.118
703CIV	53 25 S	113 51	Mar 3	32.0 W	....	......
704CIV	53 02 S	114 04	Mar 3	31.2 W	....	......
705CIV	51 34 S	115 56	Mar 4	25.9 W	....	......
706CIV	51 29 S	117 02	Mar 4	....	79.3 S	.120
707CIV	51 27 S	117 34	Mar 4	23.2 W	....	......
708CIV	49 43 S	119 50	Mar 5	17.4 W	....	......
709CIV	48 52 S	120 37	Mar 5	....	78.0 S	.136
710CIV[1]	48 36 S	120 53	Mar 5	14.9 W	....	......
711CIV[1]	46 46 S	122 28	Mar 6	10.4 W	....	......
712CIV	45 42 S	123 18	Mar 6	....	76.0 S	.154
713CIV	45 11 S	124 56	Mar 7	6.1 W	....	......
714CIV	45 08 S	125 12	Mar 7	....	75.5 S	.160
715CIV[1]	45 00 S	125 53	Mar 8	5.7 W	....	......
716CIV	44 58 S	126 04	Mar 8	....	75.6 S	.161
717CIV	44 58 S	126 09	Mar 8	5.0 W	....	......
718CIV	44 44 S	126 23	Mar 9	4.9 W	....	......
719CIV	43 58 S	126 37	Mar 9	....	74.7 S	.168
720CIV	43 44 S	126 40	Mar 9	4.0 W	....	......
721CIV[1]	42 05 S	127 36	Mar 10	2.3 W	....	......
722CIV	41 36 S	127 59	Mar 10	....	72.8 S	.185
723CIV	41 32 S	128 03	Mar 10	0.8 W	....	......
724CIV	40 26 S	128 59	Mar 11	0.5 W	....	......
725CIV	40 21 S	129 01	Mar 11	0.4 W	....	......
726CIV	39 42 S	129 26	Mar 11	....	71.1 S	.201
727CIV	39 39 S	129 28	Mar 11	0.1 E	....	......
728CIV	39 29 S	129 45	Mar 11	0.3 E	....	......
729CIV	39 57 S	129 57	Mar 12	0.4 E	....	......
730CIV	40 43 S	130 06	Mar 12	....	71.9 S	.194
731CIV	40 49 S	130 06	Mar 12	0.1 E	....	......
732CIV	41 01 S	130 08	Mar 12	0.2 E	....	......
733CIV	42 27 S	130 51	Mar 13	0.2 E	....	......
734CIV	43 30 S	130 58	Mar 13	....	73.9 S	.175
735CIV	43 50 S	130 55	Mar 13	0.2 W	....	......
736CIV	45 41 S	130 50	Mar 14	0.7 W	....	......
737CIV	46 54 S	130 49	Mar 14	....	76.5 S	.152
738CIV	47 08 S	130 51	Mar 14	1.2 W	....	......
739CIV	48 24 S	132 19	Mar 15	1.2 W	....	......
740CIV	48 56 S	132 54	Mar 15	....	77.8 S	.138
741CIV	49 09 S	132 50	Mar 15	1.2 W	....	......
742CIV[1]	50 20 S	132 56	Mar 16	1.8 W	....	......
743CIV[2]	50 23 S	132 54	Mar 16	....	78.8 S	.128
744CIV	51 00 S	132 42	Mar 16	1.4 W	....	......
745CIV	53 13 S	132 02	Mar 17	5.3 W	....	......
746CIV	54 11 S	131 54	Mar 17	....	80.9 S	.106
747CIV	54 27 S	132 07	Mar 17	6.7 W	....	......
748CIV[3]	54 37 S	132 08	Mar 17	6.1 W	....	......
749CIV	56 36 S	132 54	Mar 18	8.9 W	....	......
750CIV	56 36 S	133 17	Mar 18	....	82.6 S	.088
751CIV[1]	56 37 S	133 27	Mar 18	8.2 W	....	......
752CIV	56 40 S	134 26	Mar 19	7.9 W	....	......
753CIV	57 08 S	135 48	Mar 19	....	82.7 S	.086
754CIV	57 13 S	135 50	Mar 19	4.6 W	....	......
755CIV	57 25 S	135 53	Mar 19	5.3 W	....	......
756CIV	57 08 S	137 54	Mar 20	2.9 W	....	......
757CIV	57 11 S	138 57	Mar 20	....	82.4 S	.088
758CIV	57 12 S	139 10	Mar 20	0.2 E	....	......
759CIV	56 57 S	142 07	Mar 21	4.4 E	....	......
760CIV	56 50 S	143 28	Mar 21	....	82.1 S	.093
761CIV[1]	56 52 S	144 33	Mar 22	6.8 E	....	......
762CIV	56 45 S	144 51	Mar 22	....	81.6 S	.097
763CIV	56 41 S	146 57	Mar 23	11.8 E	....	......
764CIV[4]	56 32 S	147 24	Mar 23	....	81.3 S	.103
765CIV	54 35 S	150 40	Mar 24	14.3 E	....	......
766CIV	54 10 S	151 30	Mar 24	....	79.1 S	.126
767CIV	54 09 S	151 32	Mar 24	13.8 E	....	......
768CIV	53 07 S	153 50	Mar 25	15.8 E	....	......
769CIV	52 47 S	154 37	Mar 25	....	78.1 S	.137
770CIV	52 41 S	156 22	Mar 26	16.0 E	....	......
771CIV	52 30 S	156 54	Mar 26	....	77.3 S	.145
772CIV	51 26 S	159 54	Mar 27	17.6 E	....	......
773CIV	50 43 S	161 14	Mar 27	....	75.2 S	.163
774CIV	50 30 S	161 34	Mar 27	17.7 E	....	......
775CIV	48 49 S	163 29	Mar 28	17.4 E	....	......
776CIV	48 28 S	164 33	Mar 28	....	73.3 S	.183
777CIV	48 27 S	164 44	Mar 28	17.5 E	....	......
778CIV	48 12 S	167 08	Mar 29	17.8 E	....	......
779CIV	47 40 S	168 10	Mar 29	....	72.0 S	.192
780CIV	47 13 S	169 15	Mar 29	18.0 E	....	......
781CIV	46 39 S	170 32	Mar 30	18.3 E	....	......
782CIV	45 58 S	171 14	Mar 30	....	70.2 S	.208
783CIV	45 50 S	171 22	Mar 30	17.8 E	....	......
784CIV	44 59 S	172 31	Mar 31	17.6 E	....	......
785CIV	44 44 S	172 57	Mar 31	....	69.0 S	.217
786CIV	44 31 S	173 04	Mar 31	17.4 E	....	......
787CIV	43 38 S	173 08	Apr 1	17.2 E	....	......

[1]Mean of two positions.
[2]Declination obtained from observations on the moon.
[3]Swinging ship, starboard helm, 6 points.
[4]The horizontal-intensity values ranged from 0.098 to 0.110, indicating a disturbance of some kind.

CRUISE IV, PACIFIC OCEAN, 1916.

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	1916	°	°	c. g. s.
788CIV[1]	43 32 S	172 48	May 10	17.0 E	68.0 S	.225
789CIV	43 33 S	172 56	May 17	16.3 E	....	......
790CIV	43 41 S	174 07	May 18	17.2 E	....	......
791CIV	43 54 S	174 40	May 18	....	68.0 S	.223
792CIV	43 57 S	174 43	May 18	17.2 E	....	......
793CIV	43 07 S	174 19	May 19	17.1 E	....	......
794CIV	42 58 S	174 13	May 19	....	67.5 S	.229
795CIV	43 36 S	175 40	May 20	17.2 E	....	......
796CIV	43 43 S	176 11	May 20	....	67.6 S	.227
797CIV	43 59 S	176 34	May 21	17.6 E	....	......
798CIV	43 55 S	176 55	May 21	....	67.7 S	.226
799CIV	43 55 S	177 40	May 22	17.6 E	....	......
800CIV	44 10 S	178 51	May 22	....	67.6 S	.226
801CIV[2]	44 14 S	179 08	May 22	17.6 E	....	......
802CIV	43 57 S	181 24	May 22	17.9 E	....	......
803CIV	43 25 S	182 08	May 22	....	66.6 S	.233
804CIV	43 16 S	182 18	May 22	17.4 E	....	......
805CIV	41 47 S	184 05	May 23	16.7 E	....	......
806CIV	41 00 S	184 30	May 23	....	63.9 S	.248
807CIV	40 50 S	184 36	May 23	16.6 E	....	......
808CIV	39 57 S	185 39	May 24	16.7 E	....	......
809CIV	39 45 S	185 47	May 24	....	62.6 S	.258
810CIV	39 42 S	185 47	May 24	16.2 E	....	......
811CIV	37 28 S	186 25	May 25	15.7 E	....	......
812CIV	37 13 S	186 28	May 25	15.4 E	....	......
813CIV	36 21 S	186 48	May 25	....	59.6 S	.272
814CIV	35 59 S	187 01	May 25	15.2 E	....	......
815CIV	34 06 S	187 18	May 26	14.2 E	....	......
816CIV	33 18 S	187 21	May 26	....	56.4 S	.288
817CIV	33 04 S	187 18	May 26	14.2 E	....	......
818CIV	31 14 S	186 11	May 27	13.5 E	....	......
819CIV	30 42 S	185 06	May 27	....	53.8 S	.298
820CIV[3]	30 59 S	186 02	May 28	13.6 E	....	......
821CIV	30 58 S	186 26	May 28	....	54.1 S	.298
822CIV	30 36 S	187 45	May 29	13.2 E	....	......
823CIV	30 33 S	187 56	May 29	....	52.8 S	.301
824CIV	29 07 S	188 15	May 30	....	51.6 S	.305
825CIV	28 56 S	188 48	May 31	13.1 E	....	......
826CIV	28 42 S	189 47	May 31	....	51.3 S	.307
827CIV	28 41 S	189 54	May 31	13.3 E	....	......
828CIV	27 19 S	191 30	Jun 1	12.4 E	....	......
829CIV	26 32 S	191 36	Jun 1	....	47.7 S	.318
830CIV	26 17 S	191 37	Jun 1	12.2 E	....	......
831CIV	24 57 S	191 41	Jun 2	12.0 E	....	......
832CIV	24 33 S	191 37	Jun 2	....	45.1 S	.324
833CIV	24 24 S	191 34	Jun 2	11.8 E	....	......
834CIV	22 25 S	190 57	Jun 3	....	42.5 S	.330
835CIV	22 22 S	190 56	Jun 3	11.5 E	....	......
836CIV	19 30 S	190 04	Jun 4	....	38.4 S	.340
837CIV	18 45 S	189 05	Jun 5	10.7 E	....	......
838CIV	18 27 S	189 05	Jun 5	....	36.5 S	.345
839CIV	18 23 S	189 05	Jun 5	10.4 E	....	......
840CIV	16 08 S	189 31	Jun 6	....	32.6 S	.349
841CIV	16 04 S	189 32	Jun 6	9.8 E	....	......
842CIV	14 37 S	189 33	Jun 7	9.9 E	....	......
843CIV	14 17 S	189 06	Jun 19	10.1 E	....	......
844CIV	12 32 S	188 58	Jun 20	9.6 E	....	......
845CIV	11 30 S	189 13	Jun 20	....	24.4 S	.356
846CIV	11 15 S	189 18	Jun 20	9.4 E	....	......
847CIV	9 34 S	189 28	Jun 21	8.9 E	....	......
848CIV	9 04 S	189 20	Jun 21	....	19.7 S	.357
849CIV	8 56 S	189 22	Jun 21	8.8 E	....	......
850CIV	7 15 S	189 06	Jun 22	8.9 E	....	......
851CIV	6 14 S	188 43	Jun 22	....	14.0 S	.358
852CIV	5 51 S	188 35	Jun 22	8.6 E	....	......
853CIV	4 19 S	188 01	Jun 23	9.0 E	....	......
854CIV	3 23 S	187 50	Jun 23	....	8.2 S	.357
855CIV	3 02 S	187 46	Jun 23	8.6 E	....	......
856CIV	1 51 S	187 09	Jun 24	8.4 E	....	......
857CIV	1 12 S	186 50	Jun 24	....	3.9 S	.352
858CIV	0 55 S	186 45	Jun 24	8.5 E	....	......
859CIV	0 17 N	186 11	Jun 25	8.7 E	....	......
860CIV	0 44 N	186 03	Jun 25	....	0.4 S	.348
861CIV	0 52 N	185 58	Jun 25	8.6 E	....	......
862CIV	1 42 N	185 05	Jun 26	8.6 E	....	......
863CIV	2 27 N	184 24	Jun 26	....	3.1 N	.349
864CIV	2 40 N	184 10	Jun 26	8.3 E	....	......
865CIV	3 54 N	183 12	Jun 27	9.2 E	....	......
866CIV	4 52 N	182 45	Jun 27	....	7.6 N	.343
867CIV	5 10 N	182 37	Jun 27	8.9 E	....	......
868CIV	6 48 N	181 56	Jun 28	8.8 E	....	......
869CIV	7 52 N	181 36	Jun 28	....	13.1 N	.334
870CIV	8 15 N	181 22	Jun 28	9.0 E	....	......
871CIV	9 49 N	180 40	Jun 29	9.2 E	....	......
872CIV	10 50 N	180 14	Jun 29	....	17.9 N	.324
873CIV[4]	11 11 N	179 50	Jun 29	9.4 E	....	......
874CIV	12 44 N	179 13	Jul 1	9.1 E	....	......
875CIV	13 06 N	178 59	Jul 1	....	21.2 N	.314
876CIV	13 17 N	178 52	Jul 1	8.4 E	....	......
877CIV	14 29 N	177 36	Jul 2	9.1 E	....	......
878CIV	15 00 N	176 36	Jul 2	....	23.7 N	.312
879CIV	15 03 N	176 23	Jul 2	9.0 E	....	......
880CIV	15 35 N	174 39	Jul 3	9.0 E	....	......
881CIV	15 43 N	174 17	Jul 3	....	24.4 N	.311
882CIV	16 04 N	172 48	Jul 4	8.6 E	....	......
883CIV	16 30 N	171 51	Jul 4	....	24.6 N	.311
884CIV	16 36 N	171 37	Jul 4	8.1 E	....	......
885CIV	17 06 N	170 37	Jul 5	8.0 E	....	......
886CIV	17 28 N	169 53	Jul 5	....	25.6 N	.309
887CIV	17 37 N	169 32	Jul 5	7.5 E	....	......
888CIV	18 06 N	167 59	Jul 6	7.3 E	....	......
889CIV	18 24 N	167 14	Jul 6	....	26.0 N	.311
890CIV	18 33 N	167 01	Jul 6	6.7 E	....	......
891CIV	19 12 N	165 46	Jul 7	6.5 E	....	......
892CIV	19 32 N	165 03	Jul 7	....	26.1 N	.313
893CIV	19 41 N	164 41	Jul 7	6.7 E	....	......
894CIV	20 17 N	163 30	Jul 8	6.0 E	....	......
895CIV	20 22 N	162 50	Jul 8	....	27.7 N	.309
896CIV	20 24 N	162 36	Jul 8	5.2 E	....	......
897CIV	20 31 N	161 44	Jul 9	4.9 E	....	......
898CIV	20 24 N	160 58	Jul 9	....	28.3 N	.307
899CIV	20 22 N	160 43	Jul 9	4.8 E	....	......
900CIV	20 07 N	159 56	Jul 10	4.4 E	....	......
901CIV	19 54 N	159 15	Jul 10	....	26.5 N	.315
902CIV	19 49 N	158 59	Jul 10	4.1 E	....	......
903CIV	19 29 N	158 05	Jul 11	4.1 E	....	......
904CIV	19 17 N	157 31	Jul 11	....	25.6 N	.317
905CIV	19 08 N	157 11	Jul 11	3.7 E	....	......
906CIV	18 28 N	155 51	Jul 12	3.6 E	....	......
907CIV	18 04 N	155 02	Jul 12	....	23.1 N	.325
908CIV	17 55 N	154 44	Jul 12	3.2 E	....	......
909CIV	17 20 N	153 29	Jul 13	3.0 E	....	......
910CIV	16 58 N	152 42	Jul 13	....	21.5 N	.329
911CIV	16 50 N	152 23	Jul 13	3.2 E	....	......
912CIV	16 13 N	151 10	Jul 14	2.7 E	....	......
913CIV	15 49 N	150 25	Jul 14	....	19.0 N	.335
914CIV	15 39 N	150 07	Jul 14	2.5 E	....	......
915CIV	14 54 N	148 41	Jul 15	2.5 E	....	......
916CIV	14 38 N	147 54	Jul 15	....	16.6 N	.341
917CIV	14 32 N	147 32	Jul 15	2.2 E	....	......
918CIV	14 00 N	145 45	Jul 16	....	15.3 N	.347
919CIV	13 54 N	145 38	Jul 16	1.9 E	....	......
920CIV	13 52 N	145 30	Jul 16	2.1 E	....	......
921CIV	13 35 N	144 39	Jul 17	2.1 E	....	......
922CIV	14 38 N	144 25	Aug 8	1.3 E	....	......
923CIV	15 24 N	144 14	Aug 8	....	18.3 N	.344
924CIV	16 48 N	144 12	Aug 9	....	20.4 N	.343
925CIV	17 24 N	144 30	Aug 10	....	20.9 N	.344

[1]Swinging ship off New Brighton Beach, N. Z.
[2]Crossed 180th meridian, hence, date May 22 repeated.
[3]Mean of two positions.
[4]Crossed 180th meridian, hence date June 30 omitted.

CRUISE IV, PACIFIC OCEAN, 1916—*Concluded.*

Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.	Station	Lat.	Long. E. of Gr.	Date	Declination	Inclination	Hor. Int.
	° ′	° ′	*1916*	°	°	*c. g. s.*		° ′	° ′	*1916*	°	°	*c. g. s.*
926CIV	17 26 N	144 33	Aug 10	0.7 E	....	......	977CIV[2]	49 00 N	180 23	Aug 30	8.5 E	....	......
927CIV	17 59 N	144 19	Aug 11	....	22.3 N	.341	978CIV	49 01 N	180 26	Aug 30	....	60.9 N	.233
928CIV	18 10 N	144 14	Aug 11	0.8 E	....	......	979CIV	49 32 N	182 34	Aug 31	....	61.8 N	.228
929CIV	19 12 N	143 36	Aug 12	0.7 E	....	......	980CIV	49 34 N	182 47	Aug 31	10.1 E	....	......
930CIV	20 14 N	143 35	Aug 12	....	26.0 N	.338	981CIV	49 56 N	184 29	Sep 1	....	62.5 N	.225
931CIV	23 03 N	144 27	Aug 13	0.5 W	....	......	982CIV	49 58 N	184 37	Sep 1	11.1 E	....	......
932CIV	23 56 N	144 30	Aug 13	....	32.0 N	.328	983CIV	50 46 N	186 56	Sep 2	12.1 E	....	......
933CIV	26 29 N	144 35	Aug 14	1.6 W	....	......	984CIV	51 06 N	188 04	Sep 2	....	63.4 N	.221
934CIV	26 34 N	144 34	Aug 14	1.6 W	....	......	985CIV	51 22 N	191 04	Sep 3	14.3 E	....	......
935CIV	27 22 N	144 18	Aug 14	....	37.7 N	.317	986CIV	51 35 N	192 29	Sep 3	....	64.5 N	.217
936CIV	27 38 N	144 14	Aug 14	2.0 W	....	......	987CIV	51 38 N	192 53	Sep 3	15.4 E	....	......
937CIV	29 32 N	144 07	Aug 15	2.7 W	....	......	988CIV	51 55 N	195 34	Sep 4	16.6 E	....	......
938CIV	30 10 N	144 00	Aug 15	....	41.2 N	.313	989CIV	51 58 N	196 21	Sep 4	....	66.0 N	.206
939CIV	30 14 N	144 06	Aug 15	2.7 W	....	......	990CIV	52 28 N	198 39	Sep 5	17.9 E	....	......
940CIV	30 14 N	144 27	Aug 16	2.7 W	....	......	991CIV	52 44 N	199 56	Sep 5	....	66.6 N	.206
941CIV	30 27 N	144 13	Aug 16	....	41.9 N	.309	992CIV	52 47 N	200 14	Sep 5	18.7 E	....	......
942CIV	30 34 N	144 07	Aug 16	3.0 W	....	......	993CIV	53 22 N	203 31	Sep 6	20.4 E	....	......
943CIV	31 49 N	143 31	Aug 17	3.3 W	....	......	994CIV	53 12 N	204 49	Sep 6	....	67.6 N	.201
944CIV	32 09 N	143 50	Aug 17	....	43.6 N	.309	995CIV	52 57 N	208 10	Sep 7	21.9 E	....	......
945CIV	34 35 N	146 38	Aug 18	....	47.1 N	.294	996CIV	52 53 N	208 50	Sep 7	....	68.2 N	.199
946CIV	36 12 N	149 58	Aug 19	3.3 W	....	......	997CIV	51 33 N	212 48	Sep 8	....	68.1 N	.201
947CIV	36 40 N	150 54	Aug 19	....	48.9 N	.286	998CIV	51 16 N	213 14	Sep 8	22.2 E	....	......
948CIV	38 17 N	153 31	Aug 20	2.7 W	....	......	999CIV	49 49 N	215 28	Sep 9	23.3 E	....	......
949CIV	38 25 N	153 43	Aug 20	2.4 W	....	......	1000CIV	49 16 N	216 13	Sep 9	....	67.0 N	.210
950CIV	38 50 N	154 25	Aug 20	....	50.9 N	.274	1001CIV	47 42 N	218 15	Sep 10	22.7 E	....	......
951CIV	40 11 N	156 28	Aug 21	1.9 W	....	......	1002CIV	46 59 N	218 59	Sep 10	....	65.8 N	.218
952CIV	40 41 N	156 51	Aug 21	....	52.8 N	.270	1003CIV	46 49 N	219 09	Sep 10	22.5 E	....	......
953CIV	42 41 N	158 15	Aug 22	1.7 W	....	......	1004CIV	45 37 N	220 28	Sep 11	21.9 E	....	......
954CIV	43 03 N	158 34	Aug 22	....	55.0 N	.264	1005CIV	45 29 N	220 37	Sep 11	....	65.0 N	.224
955CIV	43 13 N	158 40	Aug 22	1.5 W	....	......	1006CIV	45 26 N	220 39	Sep 11	21.3 E	....	......
956CIV	44 24 N	158 59	Aug 23	1.5 W	....	......	1007CIV	43 44 N	221 35	Sep 12	20.9 E	....	......
957CIV	45 10 N	159 26	Aug 23	....	57.1 N	.254	1008CIV	43 07 N	221 46	Sep 12	....	63.6 N	.233
958CIV	45 21 N	159 32	Aug 23	1.7 W	....	......	1009CIV	42 26 N	221 49	Sep 12	20.1 E	....	......
959CIV	46 20 N	160 12	Aug 24	1.3 W	....	......	1010CIV	41 31 N	221 43	Sep 13	....	62.1 N	.240
960CIV	46 27 N	160 38	Aug 24	....	58.3 N	.249	1011CIV	41 42 N	221 43	Sep 13	20.2 E	....	......
961CIV	46 54 N	162 58	Aug 25	0.5 W	....	......	1012CIV	40 54 N	221 45	Sep 14	....	61.5 N	.242
962CIV	46 57 N	163 19	Aug 25	....	58.6 N	.246	1013CIV	40 51 N	221 46	Sep 14	19.7 E	....	......
963CIV	46 57 N	163 27	Aug 25	0.1 W	....	......	1014CIV	40 48 N	221 54	Sep 15	19.9 E	....	......
964CIV[1]	47 05 N	165 22	Aug 26	....	58.8 N	.245	1015CIV	40 48 N	222 03	Sep 15	....	61.6 N	.242
965CIV	47 03 N	165 21	Aug 26	0.3 E	....	......	1016CIV	40 47 N	222 27	Sep 15	19.5 E	....	......
966CIV	47 14 N	166 54	Aug 27	1.8 E	....	......	1017CIV	40 41 N	224 04	Sep 16	19.8 E	....	......
967CIV[1]	47 15 N	167 13	Aug 27	1.7 E	....	......	1018CIV	40 39 N	225 18	Sep 16	....	62.2 N	.242
968CIV	47 18 N	167 49	Aug 27	....	59.0 N	.242	1019CIV	40 38 N	225 38	Sep 16	19.2 E	....	......
969CIV	47 20 N	168 10	Aug 27	2.3 E	....	......	1020CIV	40 23 N	227 51	Sep 17	19.8 E	....	......
970CIV	47 25 N	169 02	Aug 28	1.8 E	....	......	1021CIV	40 03 N	229 07	Sep 17	....	62.5 N	.243
971CIV	47 26 N	169 24	Aug 28	....	58.9 N	.243	1022CIV	39 56 N	229 27	Sep 17	19.6 E	....	......
972CIV	47 28 N	169 40	Aug 28	3.3 E	....	......	1023CIV	39 41 N	230 05	Sep 18	19.5 E	....	......
973CIV	47 42 N	171 42	Aug 29	....	59.7 N	.239	1024CIV	39 24 N	231 14	Sep 18	....	62.2 N	.245
974CIV	47 46 N	172 03	Aug 29	4.0 E	....	......	1025CIV	38 34 N	234 24	Sep 19	....	62.1 N	.248
975CIV	48 09 N	174 24	Aug 30	5.4 E	....	......	1026CIV	38 16 N	235 33	Sep 20	....	62.4 N	.248
976CIV	48 26 N	176 02	Aug 30	....	60.2 N	.234	1027CIV	37 46 N	237 25	Sep 21	18.8 E	....	......

[1]Swinging ship. [2]Crossed 180th meridian, repeating the date Aug. 30, 1916.

SHORE MAGNETIC OBSERVATIONS FOR THE CARNEGIE WORK.

EXPLANATORY REMARKS.

The following results of shore magnetic observations, made during Cruises I and II of the *Carnegie*, 1909 to 1913, are extracted from Volume I, pages 76, 88, 91, 92, 95–97, and Volume II, pages 28, 29, 43, 44, 47, 48, 50, 51, and 56–61. The same conventions are used as in those volumes, to which reference may be made if fuller information is desired (see also pp. 257–258 of present volume). These shore magnetic results were usually obtained in connection with the comparisons of ship and land instruments made at every port of call of the vessel. Sometimes additional observations were made, in view of the disclosure of local magnetic disturbances, or for the purpose of obtaining secular-variation data.

The results of the shore observations made in connection with Cruise III are also added. Those for Cruise IV are to appear in a later volume.

RESULTS OF SHORE MAGNETIC OBSERVATIONS, 1909–1914.

AFRICA.

British South and Central Africa.

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Cape Town, *A*	33 56.8 S	18 29	Mar 24,'11	10.2, 12.2, 14.2	27 38.0 W			10.9, 11.7	.17576	4		C II
			Mar 24, 11	15.8, 17.4	27 35.4 W			14.7, 15.4	.17570	4		C II
			Mar 24, 11					16.3, 16.9	.17582	4		C II
			Mar 25, 11	9.0, 11.0	27 38.6 W			9.6, 10.5	.17595	2		C II
			Mar 25, 11	12.2, 14.0	27 35.7 W			12.7, 13.5	.17585	2		C II
			Mar 27, 11	9.6, 12.4	27 36.5 W			10.2, 11.4	.17594	2		C II
			Mar 27, 11	13.2, 15.6	27 34.7 W			13.8, 15.0	.17577	2		C II
			Apr 3, 11			14.1, 14.7	60 07.6 S				EI 2	C II
			Apr 4, 11			9.5, 10.2	60 04.7 S				201.12	C II
			Apr 4, 11			10.6, 11.0	60 04.6 S				201.12	C II
			Apr 18, 11	12.8, 13.3	27 33.7 W					4		C II
			Apr 18, 11	13.8, 15.5	27 34.2 W					4		C II
Cape Town, *B*	33 56.8 S	18 29	Mar 25, 11	9.0, 11.0	27 38.9 W			9.6, 10.6	.17611	8		C II
			Mar 25, 11	12.2, 14.0	27 35.6 W			12.7, 13.5	.17584	8		C II
			Mar 27, 11	9.6, 12.4	27 36.8 W			10.2, 11.4	.17595	4		C II
			Mar 27, 11	13.2, 15.6	27 35.4 W			13.9, 15.0	.17576	4		C II
			Mar 28, 11	12.8, 16.0	27 35.5 W			14.5	.17586	8		C II
			Mar 29, 11	11.2, 15.1	27 38.2 W			13.5	.17596	8		C II
			Mar 30, 11	9.9, 16.6	27 37.1 W			14.9, 16.0	.17621	8		C II
			Apr 3, 11			10.2, 11.5	60 03.3 S				201.12	C II
			Apr 3, 11			13.3, 14.2	60 05.4 S				201.12	C II
			Apr 4, 11			9.6, 10.2	60 04.4 S				EI 2	C II
			Apr 4, 11			11.0, 12.8	60 04.6 S				EI 2	C II
			Apr 4, 11			14.2	60 05.1 S				EI 2	C II
			Apr 5, 11			10.7, 11.9	60 05.0 S				EI 2	C II
			Apr 5, 11			13.2, 13.9	60 04.6 S				EI 2	C II
			Apr 5, 11			15.1	60 04.8 S				EI 2	C II
Cape Town, *C*	33 56.8 S	18 29	Mar 24, 11	10.2, 12.2, 14.2	27 39.2 W			10.8, 11.6	.17604	2		C II
			Mar 24, 11	15.8, 17.4	27 37.6 W			14.7, 15.4	.17596	2		C II
			Mar 24, 11					16.3, 16.9	.17602	2		C II
			Mar 25, 11	9.0, 11.0	27 43.1 W			9.6, 10.6	.17596	4		C II
			Mar 25, 11	12.2, 14.0	27 40.4 W			12.7, 13.6	.17590	4		C II
			Mar 27, 11	9.6, 12.4	27 41.2 W			10.3, 11.4	.17602	8		C II
			Mar 27, 11	13.2, 15.6	27 39.4 W			13.9, 15.0	.17586	8		C II
			Mar 31, 11	9.8, 13.8	27 41.0 W			11.6, 12.6	.17624	8		C II
			Mar 31, 11	14.5, 16.6	27 37.0 W			15.2, 16.1	.17619	8		C II
			Apr 3, 11			11.2	60 02.8 S				172.156	C II
			Apr 3, 11			14.2	60 02.9 S				172.256	C II
			Apr 6, 11			10.9, 11.6	60 04.8 S				EI 2	C II
			Apr 6, 11			15.6	60 03.9 S				EI 2	C II

AFRICA.

BRITISH SOUTH AND CENTRAL

EUROPE.

GREAT BRITAIN.

	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Truro	50 15.4 N	354 58	Oct 2,'13	12.8, 14.6	[illegible]	11.3	66 28.8 N	13.4, 14.3	.18772	14	14.1256	C II
			Oct 3, 13	10.0, 11.4	17 16.8 W	12.8 ...	66 27.8 N	10.4, 11.0	[illegible]	14	14.1256	C II
Falmouth, A	50 10 N	354 57	Oct 20, 09	10.0, 11.9	17 47.1 W	14.5	66 34.6 N	10.6, 11.5	[illegible]	2	178.25	C I
			Oct 21, 09			16.5(wt.½)	66 35.8 N				189.9,10	C I
			Oct 22, 09	13.3, 14.9	17 47.8 W	9.3, 11.1	66 32.7 N	13.7, 14.5	.18756	4	201.12	C I
			[illegible]			16.5(wt.½)	66 33.0 N				203.66	C I
	50 09.6 N	354 57	Sep 16, 13	11.2, 13.8, 14.8	17 14.1 W			13.2, 13.4	[illegible]	4		[illegible]
			Sep 16, 13	16.9, 17.0	17 10.8 W			15.2, 16.3	.18802	4		C II
			Sep 17, 13	9.0, 10.9	17 12.4 W			9.7, 10.6	.18782	4		C II
			Sep 17, 13					12.1, 13.4	.18805	2		C II
			Sep 17, 13					14.7, 15.5	[illegible]	2		C II
			Sep 17, 13					16.6, 17.4	[illegible]	2		C II
			Sep 18, 13					9.7, 10.5	.18792	2		[illegible]
			Sep 18, 13					11.5, 12.9	.18784	2		C II
			Sep 18, 13					14.0, 14.8	.18803	2		C II
			Sep 19, 13			10.7, 11.4	66 28.3 N				EI 3	C II
			Sep 19, 13			11.9, 12.4	66 27.3 N				EI 3	C II
			Sep 19, 13			13.3, 13.8	66 27.4 N				EI 3	C II
			Sep 19, 13			14.3, 14.8	[illegible]				[illegible]	[illegible]
			Sep 20, 13			10.2, 10.6	66 26.0 N				EI 2	C II
			Sep 20, 13			10.8, 11.1	[illegible]				EI 2	[illegible]
			Sep 20, 13			11.4, 11.8	66 28.2 N				EI 2	C II
			Sep 20, 13			12.6, 13.0	66 26.0 N				EI 2	C II
			Sep 22, 13			9.6, 9.9	66 26.8 N				EI 2	C II
			Sep 22, 13			10.2, 10.9	66 27.4 N				EI 2	[illegible]
			Sep 22, 13			11.4, 12.8	66 26.6 N				EI 2	C II
			Sep 22, 13			13.0, 13.2	66 25.6 N				EI 3	C II
			Sep 24, 13	9.9, 11.4, 12.3	17 13.5 W			10.5, 11.3	[illegible]	4		C II
			Sep 24, 13	13.4, 13.8, 14.7	17 14.2 W			12.6, 13.1	[illegible]	4		C II
			Sep 24, 13					13.9, 14.4	[illegible]	4		C II
			Sep 30, 13			15.0, 15.6	66 24.9 N				EI 3	C II
Falmouth, B	50 10 N	354 57	Oct 21, 09	10.6, 14.5	17 45.0 W	16.5	66 32.8 N	12.8, 13.8	.18730	4	201.12	C I
			Oct 22, 09			10.1	66 35.9 N				189.9,10	C I
	50 09.6 N	354 57	Sep 18, 13	8.9, 10.8, 11.2	17 10.7 W			9.6, 10.5	.18788	4		C II
			Sep 18, 13	13.3, 13.6, 15.2	17 15.7 W			11.5, 12.8	.18781	4		C II
			Sep 18, 13					14.0, 14.8	.18798	4		C II
			Sep 22, 13			9.2, 10.6	66 27.1 N				EI 3	C II
			Sep 22, 13			12.1, 13.1	66 28.1 N				EI 3	C II
			Sep 22, 13			14.9, 15.5	66 26.5 N				EI 3	C II
			Sep 22, 13			16.0, 16.4	66 26.9 N				EI 3	C II
			Sep 24, 13	9.9, 11.4, 12.3	17 12.4 W			10.4, 11.1	.18792	14		C II
			Sep 24, 13	13.4, 13.6, 14.7	17 13.8 W			12.6, 13.1	[illegible]	14		C II
			Sep 24, 13					13.9, 14.4	.18796	14		[illegible]
			Sep 25, 13			9.4, 10.0	66 26.1 N				EI 3	C II
			Sep 25, 13			10.9, 11.9	66 25.5 N				EI 3	C II
			Sep 25, 13			12.8	66 25.1 N				EI 3	[illegible]
Falmouth, C	50 09.6 N	354 57	Sep 15, 13	16.0, 16.9, 17.8	17 10.8 W					4		C II
			Sep 16, 13	13.8, 14.8	17 11.7 W			13.2, 13.4	.18775	3		C II
			Sep 16, 13	16.9, 17.1	[illegible]			15.2, 16.3	.18783	3		[illegible]
			Sep 17, 13	11.6, 12.8, 14.3	17 15.4 W			12.1, 13.4	.18789	4		C II
			Sep 17, 13	15.8, 16.2, 17.7	17 10.7 W			14.7, 15.5	.18806	4		[illegible]
			Sep 17, 13					16.6, 17.3	.18799	4		[illegible]

EUROPE.

GREAT BRITAIN—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Falmouth, *C—Continued*	50 09.6 N	354 57	Sep 17,'13	9.1, 10.9, 11.6	17 12.4 W			9.7, 10.6	.18772	2		C II
			Sep 17, 13	13.8, 14.3, 15.8	17 12.5 W					2		C II
			Sep 17, 13	16.2, 17.7	17 09.4 W					2		C II
			Sep 18, 13	8.9, 10.8, 11.2	17 09.6 W					2		C II
			Sep 18, 13	13.3, 13.6, 15.2	17 14.6 W					2		C II
			Sep 19, 13			11.1, 11.6	66 26.7 N				EI 2	C II
			Sep 19, 13			12.0, 12.3	66 26.8 N				EI 2	C II
			Sep 19, 13			13.2, 13.5	66 26.2 N				EI 2	C II
			Sep 19, 13			13.9, 14.2	66 26.2 N				EI 2	C II
			Sep 20, 13			9.9, 10.5	66 27.3 N				EI 3	C II
			Sep 20, 13			11.1, 11.6	66 27.7 N				EI 3	C II
			Sep 20, 13			12.2	66 27.5 N				EI 3	C II
			Sep 20, 13			12.9, 13.4	66 28.0 N				EI 3	C II
			Sep 30, 13			14.9, 15.2	66 25.2 N				EI 2	C II
			Sep 30, 13			15.4, 15.7	66 25.2 N				EI 2	C II
Falmouth Observatory	50 09.0 N	354 55	Oct 22, 09	10.2, 12.3, 13.6	17 48.7 W	16.5	66 31.0 N	10.7, 11.7	.18767	2	201.12	C I
			Oct 22, 09					14.3, 15.2	.18767	2		C I
			Oct 29, 09	11.1, 14.5	17 48.9 W	10.1, 16.3	66 30.8 N	11.8, 13.8	.18765	4	201.12	C I
			Sep 22, 13			10.0, 10.9	66 19.7 N				201.12	C II
			Sep 22, 13			11.8	66 22.6 N				201.12	C II
			Sep 24, 13	10.3, 12.0, 13.1	17 15.4 W			10.7, 11.7	.18794	2		C II
			Sep 24, 13	14.5, 14.9, 16.4	17 14.0 W			13.5, 14.2	.18808	2		C II
			Sep 24, 13					15.2, 16.0	.18802	2		C II
St. Anthony	50 08 N	355 00	Oct 25, 09			12.1	66 36.0 N	12.8	*.18745*	*803*	203.56	C I
			Oct 26, 09	11.7, 13.3	17 54.7 W	12.1	66 32.5 N	12.6	*.18741*	*803*	203.56	C I
			Oct 2, 13	13.7, 15.7	17 23.6 W	11.6, 11.9	66 26.0 N	14.3, 15.2	.18783	2	EI 2	C II
			Oct 3, 13	12.9, 14.8	17 24.5 W	16.5, 16.8	66 25.8 N	13.5, 14.3	.18786	2	EI 2	C II
Porthallow	50 04.3 N	354 55	Oct 2, 13	15.0, 16.4	17 16.1 W	10.4, 10.9	66 25.3 N	15.5, 16.1	.18794	4	201.1	C II
			Oct 3, 13	9.3, 10.6	17 12.2 W	13.8	66 24.8 N	9.8, 10.4	.18774	4	201.1	C II

NORWAY.

Station	Latitude	Long. East of Gr.	Date	Decl. Local Mean Time	Decl. Value	Incl. L. M. T.	Incl. Value	Hor. Int. L. M. T.	Hor. Int. Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Skibnoes Fiord	70 44.3 N	23 23	Jul 20,'14	8.6, 10.3	1 25.2 W	10.9, 11.2	77 03.9 N	9.1, 9.8	.11648	25	EI 25	C III
Melko Island	70 44.2 N	23 35	Jul 21, 14	1.1, 2.6	1 30.6 W	3.9 to 5.3	77 00.7 N	1.5, 2.2	.11708	25	EI 25	C III
Hammerfest, *A*	70 40.3 N	23 40	Jul 7, 14	13.9, 16.4	1 38.8 W			14.6, 15.9	.11772	25		C III
			Jul 8, 14	9.2, 11.6	1 30.0 W			9.7, 10.9	.11677	25		C III
			Jul 8, 14	12.0, 14.4	1 35.6 W			12.4, 14.0	.11696	25		C III
			Jul 8, 14	14.8, 16.5	1 35.8 W			15.1, 16.0	.11712	5		C III
			Jul 9, 14	9.5, 11.7	1 31.3 W			10.1, 11.3	.11689	5		C III
			Jul 9, 14	12.2, 15.0	1 37.5 W			12.8, 14.5	.11732	5		C III
			Jul 10, 14	20.5, 21.0	1 36.2 W	10.7 to 14.6	76 56.1 N			25	EI 3	C III
			Jul 10, 14	20.6 to 20.9(dv)	1 35.9 W	15.4 to 17.8	77 00.4 N			25	EI 25	C III
			Jul 15, 14	19.2 to								
			Jul 16, 14	19.1(dv)	1 31.4 W					25		C III
			Jul 20, 14			11.9 to 21.8	76 57.7 N				EI 3	C III
			Jul 21, 14			0.8 to 5.6	76 59.3 N				EI 3	C III
			Jul 23, 14	9.4, 11.2, 11.6	1 32.3 W			9.8, 10.9	.11690	5		C III
			Jul 23, 14	14.6, 14.8, 16.5	1 37.0 W			11.9, 14.2	.11697	5		C III
			Jul 23, 14					15.2, 16.1	.11736	5		C III
Hammerfest, *B*	70 40.3 N	23 40	Jul 7, 14	13.9, 16.4	1 44.2 W			14.6, 15.9	.11760	5		C III
			Jul 8, 14	11.6	1 37.4 W			9.7, 10.9	.11671	5		C III
			Jul 8, 14	12.0, 14.4	1 41.2 W			12.4, 14.0	.11688	5		C III
			Jul 8, 14	14.8, 16.5	1 42.1 W			15.1, 16.0	.11704	25		C III
			Jul 9, 14	9.5, 11.7	1 36.0 W			10.1, 11.3	.11681	25		C III
			Jul 9, 14	12.2, 15.0	1 42.3 W			12.8, 14.5	.11720	25		C III
			Jul 10, 14			10.7 to 14.6	76 57.6 N				EI 25	C III
			Jul 10, 14			15.4 to 17.8	76 59.6 N				EI 3	C III
			Jul 11, 14	3.5, 8.8	1 29.0 W	9.7 to 10.2	77 01.6 N	11.0, 12.0	.11670	25	EI 25	C III
			Jul 11, 14	3.6 to 8.5(dv)	1 29.7 W	12.6 to 14.6	77 01.5 N	15.2, 16.3	.11700	25	EI 25	C III
			Jul 11, 14			17.0 to 17.4	77 00.6 N				EI 25	C III
			Jul 13, 14			9.2 to 12.0	77 03.2 N	10.2, 10.8	.11676	25	EI 25	C III
			Jul 13, 14			14.0 to 14.8	77 02.6 N	12.4, 13.6	.11672	25	EI 25	C III
			Jul 13, 14			16.3, 16.5	77 01.1 N	15.3, 15.9	.11693	25	EI 25	C III
			Jul 14, 14	9.4, 11.2	1 36.4 W			9.9, 10.9	.11676	25		C III
			Jul 14, 14	11.6, 13.0	1 42.6 W			11.9, 12.6	.11668	25		C III
			Jul 14, 14	13.7, 15.3	1 42.0 W			14.1, 14.8	.11706	25		C III
			Jul 14, 14	15.5, 16.9	1 40.4 W			15.9, 16.6	.11732	25		C III

EUROPE.

NORWAY—*Concluded.*

Station	Latitude	Long East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Hammerfest, *B—Continued* ..	70 40.3 N	23 40	Jul 15,'14	9.0, 10.8, 11.0	1 37.5 W	....	....	9.4, 10.4	.11668	25	....	C III
			Jul 15, 14	12.9, 13.8	1 40.6 W	....	....	11.3, 12.5	.11672	25	....	C III
			Jul 17, 14	9.5, 11.5	1 40.0 W	....	....	9.9, 11.1	.11678	25	....	C III
			Jul 17, 14	11.7, 13.6	1 43.3 W	....	....	12.2, 13.2	.11687	25	....	C III
			Jul 17, 14	14.6, 16.5	1 44.0 W	....	....	15.1, 16.1	.11703	25	....	C III
			Jul 17, 14	16.6, 18.4	1 44.5 W	....	....	17.0, 18.0	.11714	25	....	C III
			Jul 17, 14	18.5 to 20.8(dv)	1 43.9 W	....	....	....	....	25	....	C III
			Jul 20, 14	8.6 to				9.0 to				
			Jul 21, 14	5.5(22)	1 38.9 W	....	....	6.0(19)	.11703	5	....	C III
			Jul 23, 14	9.4, 11.2	1 36.0 W	....	....	9.8, 10.8	.11680	25	....	C III
			Jul 23, 14	11.6, 14.6	1 41.2 W	....	....	11.9, 14.2	.11686	25	....	C III
			Jul 23, 14	14.8, 16.5	1 41.5 W	....	....	15.2, 16.1	.11720	25	....	C III
Hammerfest, *Meridianstötten*	70 40.2 N	23 40	Jul 6, 14	10.0, 12.1, 12.9	1 26.5 W	14.7 to 15.2	76 53.0 N	10.6, 11.7	.11754	25	EI 25	C III
Hasion Island..............	70 39.7 N	23 28	Jul 20, 14	18.6, 20.9, 21.1	1 53.0 W	22.2, 22.6	77 00.2 N	20.0, 20.6	.11799	25	EI 25	C III
Hielmen Island.............	70 39.3 N	23 19	Jul 20, 14	14.4, 16.0	1 58.0 W	16.5 to 17.0	76 53.8 N	15.1, 15.7	.11758	25	EI 25	C III

NORTH AMERICA.

UNITED STATES.

Station	Latitude	Long East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Greenport, *A*.............	41 06.4 N	287 38	Jun 28,'09	10.1, 11.6	10 50.2 W	8.9	72 06.2 N	10.5, 11.2	.18320	4	201.12	JPA
			Jun 10, 10	....	....	9.9, 10.5	72 07.6 N	....	....	....	201.12	C II
			Jun 10, 10	....	....	11.1	72 07.8 N	....	....	....	201.12	C II
			Jun 11, 10	12.9, 13.1, 14.9	11 00.2 W	....	....	13.7, 14.4	.18305	4	....	C II
			Jun 11, 10	15.2, 15.6, 15.8	10 59.7 W	....	....	16.4, 17.0	.18318	4	....	C II
			Jun 14, 10	14.4, 16.4, 17.7	10 58.1 W	....	....	14.9, 15.7	.18314	4	....	C II
			Jun 14, 10	....	....	....	....	17.0	.18312	4	....	C II
			Jun 15, 10	9.6, 11.4, 12.7	10 59.4 W	....	....	10.1, 10.9	.18278	4	....	C II
			Jun 15, 10	....	....	....	....	11.8	.18290	4	....	C II
			Jun 16, 10	....	....	10.1, 10.6	72 06.9 N	....	....	....	201.12	C II
			Jun 16, 10	....	....	11.7	72 05.8 N	....	....	....	201.12	C II
			Dec 17, 13	14.2, 15.3	11 21.9 W	12.5, 12.8	72 11.4 N	14.6, 15.0	.18113	4	EI 2	C II
			Dec 17, 13	....	....	13.0, 13.4	72 11.2 N	....	....	....	EI 2	C II
			Dec 18, 13	9.3, 10.4	11 17.9 W	11.2, 11.4	72 11.6 N	9.6, 10.1	.18098	4	EI 2	C II
			Dec 18, 13	....	....	11.6, 11.8	72 11.4 N	....	....	....	EI 2	C II
			Oct 13, 14	9.5, 11.0	11 21.1 W	11.3 ...	72 12.5 N	9.9, 10.5	.18044	25	EI 25	C III
			Oct 13, 14	13.6, 14.7	11 24.2 W	15.1, 15.3	72 13.0 N	13.8, 14.4	.18051	25	EI 25	C III
Greenport, *B*.............	41 06.4 N	287 38	Jun 10, 10	12.9, 13.3, 15.4	11 03.2 W	....	....	13.9, 14.8	.18333	4	....	C II
			Jun 10, 10	15.6, 16.1, 16.4	11 02.7 W	....	....	16.8, 17.5	.18325	4	....	C II
			Jun 11, 10	....	....	10.0, 10.7	72 07.0 N	....	....	....	201.12	C II
			Jun 11, 10	....	....	11.2	72 07.1 N	....	....	....	201.12	C II
			Jun 13, 10	15.0, 16.6	11 00.7 W	....	....	15.5, 16.2	.18338	4	....	C II
			Jun 13, 10	....	....	....	....	17.3, 18.1	.18332	4	....	C II
			Jun 14, 10	9.7, 10.8, 11.7	10 59.1 W	....	....	10.2, 11.3	.18297	4	....	C II
			Jun 17, 10	....	....	10.0, 10.9	72 06.8 N	....	....	....	201.12	C II
			Jun 17, 10	....	....	12.6	72 04.8 N	....	....	....	201.12	C II
Dering Harbor..............	41 05 N	287 39	Dec 17, 13	14.3, 16.2	11 38.2 W	12.3	72 18.8 N	14.8, 15.8	.18015	2	201.12	C II
			Dec 18, 13	9.6, 11.6	11 39.0 W	12.2	72 17.3 N	10.2, 11.2	.17994	2	201.12	C II
			Oct 14, 14	11.7, 12.8	11 42.6 W	11.2, 13.6	72 20.2 N	12.0, 12.5	.17951	25	EI 25	C III
			Oct 14, 14	13.9, 14.9	11 43.6 W	15.3, 16.4	72 19.4 N	14.2, 14.6	.17962	25	EI 25	C III
New York, *Bronx Park, A**..	40 51.7 N	286 07	Jul 14, 09	13.3, 14.7	10 12.4 W	12.0	72 02.5 N	13.7, 14.4	.18552	4	201.12	JPA
			Jul 26, 09	15.0, 19.4	10 08.0 W	....	....	....	....	4	....	JPA
			Feb 25, 10	....	....	15.6	72 07.9 N	....	....	....	201.12	C I
			Feb 26, 10	....	....	12.5, 14.7	72 05.8 N	....	....	....	201.12	C I
			Feb 28, 10	....	....	....	....	12.3, 14.2	.18516	2	....	C I
			Feb 28, 10	....	....	....	....	15.0, 15.7	.18514	2	....	C I
			Mar 1, 10	....	....	....	....	11.0, 11.7	.18496	4	....	C I
			Mar 1, 10	....	....	....	....	13.9, 14.4	.18509	4	....	C I
			Mar 3, 10	....	....	....	....	11.3, 12.0	.18513	4	....	C I
			Mar 3, 10	....	....	....	....	14.4, 15.3	.18530	2	....	C I
			Mar 4, 10	11.0 to 12.3(6)	10 11.8 W	....	....	....	....	2	....	C I
			Mar 4, 10	13.7 to 15.4(7)	10 16.6 W	....	....	....	....	4	....	C I
			Mar 10, 10	13.7, 14.3	10 16.7 W	....	....	....	....	4	....	C I
			Mar 12, 10	....	....	10.5	72 06.2 N	....	....	....	201.12	C I

*Local disturbance.

NORTH AMERICA.

UNITED STATES—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
New York, *Bronx Park, B**..	40 51.7 N	286 07	Feb 24,'10			15.2	72 07.4 N				201.12	C I
			Feb 25, 10			11.4, 13.3	72 07.7 N				201.12	C I
			Feb 28, 10					12.3, 14.1	.18527	4		C I
			Feb 28, 10					15.0, 15.8	.18529	4		C I
			Mar 1, 10					11.2, 12.1	.18516	2		C I
			Mar 1, 10					13.7, 14.6	.18518	2		C I
			Mar 3, 10					11.2, 12.2	.18531	2		C I
			Mar 3, 10					14.2, 15.1	.18522	4		C I
			Mar 4, 10	11.0 to 12.3(6)	11 11.9 W					4		C I
			Mar 4, 10	13.7 to 15.5(7)	11 17.7 W					2		C I
			Mar 9, 10	11.1, 12.1, 16.0	11 13.0 W					4		C I
			Mar 11, 10	9.8 to 12.0(6)	11 10.9 W	14.8	72 07.3 N			4	201.12	C I

SOUTH AMERICA.

ARGENTINA.

Station	Latitude	Long. East of Gr.	Date	Decl. L. M. T.	Decl. Value	Incl. L. M. T.	Incl. Value	H. I. L. M. T.	H. I. Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Pilar, *Pier 1*	31 40.1 S	296 07	Jan 30,'11	9.2, 11.3	9 09.4 E			10.8, 15.1	.25702	2		C II
			Jan 30, 11	14.6, 16.6	9 13.2 E			16.0	.25693	2		C II
			Jan 31, 11	9.0, 11.2	9 09.6 E			9.7, 10.7	.25703	4		C II
			Jan 31, 11	14.4, 17.6	9 10.1 E			16.2, 17.1	.25658	4		C II
Pilar, *Pier 8*	31 40.1 S	296 07	Jan 23, 11			15.1, 16.6	25 49.6 S				201.12	C II
			Jan 24, 11			9.7	25 49.0 S				201.12	C II
			Feb 2, 11			9.6, 10.9	25 50.9 S				201.12	C II
			Feb 2, 11			12.0	25 50.1 S				201.12	C II
			Feb 2, 11			16.0, 17.0	25 51.6 S				EI 2	C II
			Feb 2, 11			17.6	25 51.8 S				EI 2	C II
Pilar, *B*	31 40.1 S	296 07	Jan 28, 11	9.9, 12.1	9 10.3 E			10.4, 11.4	.25644	4		C II
			Jan 28, 11	14.4, 16.4	9 09.7 E			15.0, 16.0	.25662	4		C II
			Jan 31, 11	9.0, 11.2	9 08.6 E			9.7, 10.6	.25694	2		C II
			Jan 31, 11	14.4, 17.6	9 09.6 E			16.3, 17.2	.25651	2		C II
			Feb 1, 11			13.9, 14.5	25 52.3 S				EI 2	C II
			Feb 1, 11			15.1, 16.2	25 54.0 S				EI 2	C II
			Feb 2, 11			15.8, 17.0	25 55.1 S				201.12	C II
			Feb 2, 11			17.6	25 55.3 S				201.12	C II
Pilar, *C*	31 40.1 S	296 07	Jan 28, 11	9.9, 12.1	9 10.0 E			10.4, 11.3	.25658	2		C II
			Jan 28, 11	14.3, 16.4	9 09.2 E			14.9, 15.9	.25670	2		C II
			Jan 30, 11	9.2, 11.3	9 07.8 E			9.8, 10.8	.25664	4		C II
			Jan 30, 11	14.6, 16.6	9 11.2 E			15.1, 16.0	.25636	4		C II
			Feb 1, 11			14.1, 15.0	25 52.6 S				201.12	C II
			Feb 1, 11			16.2	25 54.0 S				201.12	C II
			Feb 2, 11			9.5, 11.0	25 53.1 S				EI 2	C II
			Feb 2, 11			12.0	25 53.1 S				EI 2	C II
Buenos Aires, Victoria, *1911*	34 27.3 S	301 27	Feb 11, 11	16.4, 16.6	6 02.8 E					4		C II

BRAZIL.

Station	Latitude	Long. East of Gr.	Date	Decl. L. M. T.	Decl. Value	Incl. L. M. T.	Incl. Value	H. I. L. M. T.	H. I. Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Pinheiro, *A*	1 17.9 S	311 31	Sep 29,'10	9.4, 11.1	7 54.5 W			10.0, 10.8	.29050	4		C II
			Sep 30, 10	9.4, 10.9	7 50.9 W			9.9, 10.5	.29057	4		C II
			Sep 30, 10	12.9, 14.6	7 52.1 W			13.3, 14.0	.29066	4		C II
			Oct 1, 10	9.3, 10.8	7 53.0 W			9.8, 10.4	.29087	2		C II
			Oct 1, 10	12.7, 14.2	7 51.5 W			13.1, 13.7	.29060	2		C II
			Oct 1, 10	14.3, 15.6	7 52.4 W			14.7, 15.3	.29049	2		C II
			Oct 3, 10	9.2, 10.7	7 52.0 W			9.6, 10.3	.29133	2		C II
			Oct 3, 10	12.9, 14.2	7 52.2 W			13.3, 13.9	.29082	2		C II
			Oct 3, 10	14.6, 15.8	7 53.4 W			14.9, 15.5	.29060	2		C II
			Oct 6, 10			10.1, 10.7	23 03.1 N				201.12	C II
			Oct 6, 10			11.2, 11.8	23 02.2 N				201.12	C II
			Oct 6, 10			13.7, 14.3	23 08.8 N				201.12	C II
			Oct 6, 10			14.9, 15.6	23 13.4 N				201.12	C II
Pinheiro, *B*	1 17.9 S	311 31	Oct 1, 10	9.3, 10.7	7 53.1 W			9.8, 10.4	.29087	4		C II
			Oct 1, 10	12.7, 14.1	7 52.7 W			13.1, 13.7	.29064	4		C II
			Oct 1, 10	14.3, 15.6	7 52.8 W			14.6, 15.2	.29050	4		C II

*Local disturbance.

SOUTH AMERICA.

SOUTH AMERICA.

BRAZIL—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Rio de Janeiro, *A*	22 58.7 S	316 49	Dec 9,'10	10.5, 12.3	9 49.2 W			11.1, 12.0	.24690	4		C II
			Dec 9, 10	14.5, 16.0	9 48.9 W			14.9, 15.6	.24696	4		C II
			Dec 9, 10	16.2, 17.6	9 50.4 W			16.6, 17.2	.24690	4		C II
			Dec 10, 10	8.8, 10.3	9 51.6 W			9.2, 9.8	.24700	2		C II
			Dec 10, 10	12.5, 14.4	9 48.8 W			12.9, 14.1	.24736	2		C II
			Dec 10, 10	14.7, 16.1	9 51.6 W			15.1, 15.7	.24679	2		C II
			Dec 12, 10	9.1, 10.8, 12.5	9 48.0 W			9.6, 10.3	.24724	2		C II
			Dec 12, 10	13.9, 14.2, 15.7	9 50.0 W			12.8, 13.5	.24740	2		C II
			Dec 12, 10	17.3, 17.6, 18.0	9 49.8 W			14.5, 15.2	.24712	2		C II
			Dec 12, 10	18.3	9 49.6 W					2		C II
			Dec 13, 10			14.4, 15.2	14 47.8 S				EI 2	C II
			Dec 13, 10			15.8, 16.3	14 49.2 S				EI 2	C II
			Dec 14, 10			10.6, 12.8	14 48.8 S				201.12	C II
			Dec 14, 10			13.6, 14.3	14 49.3 S				201.12	C II
Rio de Janeiro, *B*	22 58.7 S	316 49	Dec 12, 10	9.1, 10.8	9 49.2 W			9.6, 10.4	.24728	4		C II
			Dec 12, 10	12.4, 13.8	9 48.0 W			12.9, 13.5	.24710	4		C II
			Dec 12, 10	14.2, 15.7	9 51.3 W			14.6, 15.2	.24702	4		C II
			Dec 13, 10			14.2, 15.1	14 49.0 S				201.12	C II
			Dec 13, 10			15.7, 16.4	14 51.0 S				201.12	C II
			Dec 14, 10			10.6, 13.0	14 49.7 S				EI 2	C II
			Dec 14, 10			13.9, 14.8	14 50.2 S				EI 2	C II
			Dec 14, 10			15.7, 16.5	14 50.4 S				EI 2	C II
			Dec 15, 10			9.5, 10.2	14 48.6 S				EI 2	C II
			Dec 15, 10			11.0, 11.5	14 50.4 S				EI 2	C II
			Dec 15, 10			13.8, 14.5	14 51.7 S				EI 2	C II
			Dec 15, 10			15.3, 16.1	14 51.7 S				EI 2	C II
Rio de Janeiro, *C*	22 58.7 S	316 49	Dec 9, 10	10.6, 12.4	9 49.4 W			11.1, 11.9	.24712	2		C II
			Dec 9, 10	14.5, 16.0	9 48.4 W			14.9, 15.6	.24712	2		C II
			Dec 9, 10	16.2, 17.6	9 50.2 W			16.6, 17.2	.24675	2		C II
			Dec 10, 10	8.7, 10.3	9 51.7 W			9.2, 9.9	.24687	4		C II
			Dec 10, 10	12.5, 14.4	9 48.7 W			13.0, 14.1	.24707	4		C II
			Dec 10, 10	14.6, 16.1	9 51.3 W			15.1, 15.7	.24672	4		C II

CHILE.

Station	Latitude	Long. East of Gr.	Date	Decl. L. M. T.	Decl. Value	Incl. L. M. T.	Incl. Value	H. I. L. M. T.	H. I. Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Coronel, *A*	37 01.9 S	286 50	Nov 29,'12	11.7, 15.2, 15.7	15 45.8 E			12.6, 14.8	.26656	2		C II
			Nov 29, 12	17.9, 18.2	15 44.0 E			16.2, 17.4	.26649	2		C II
			Nov 30, 12	10.0, 12.0	15 43.6 E			10.4, 11.6	.26654	2		C II
			Nov 30, 12	12.7, 13.6	15 45.1 E			14.0, 15.4	.26674	19		C II
			Nov 30, 12	15.8, 16.2, 18.3	15 45.6 E			16.6, 17.8	.26664	19		C II
			Dec 1, 12	9.8, 11.6	15 42.8 E			10.2, 11.3	.26668	19		C II
			Dec 2, 12			11.7, 16.0	35 29.5 S				19.1256	C II
			Dec 3, 12			10.1	35 29.4 S				19.1256	C II
Coronel, *B*	37 01.9 S	286 50	Nov 28, 12	6.0, 7.0, 9.6	15 44.7 E			10.0, 10.9	.26678	2		C II
			Nov 28, 12	13.1, 17.5, 18.6	15 46.0 E			11.5, 12.6	.26673	2		C II
			Nov 28, 12					14.3, 15.5	.26656	2		C II
			Nov 28, 12					16.6	.26665	2		C II
			Nov 29, 12	11.7, 15.2, 15.7	15 44.5 E			12.5, 14.8	.26676	19		C II
			Nov 29, 12	17.9, 18.2	15 44.0 E			16.2, 17.3	.26666	19		C II
			Nov 30, 12	10.0, 12.0	15 44.2 E			10.4, 11.6	.26690	19		C II
			Nov 30, 12	12.7, 13.6	15 45.2 E			14.1, 15.4	.26670	2		C II
			Nov 30, 12	15.8, 16.2, 18.3	15 45.6 E			16.6, 17.7	.26672	2		C II
			Dec 1, 12	9.8, 11.6	15 42.6 E			10.2, 11.3	.26684	2		C II
			Dec 3, 12			11.8, 14.4	35 29.7 S				19.1256	C II
			Dec 3, 12			16.3	35 31.7 S				19.1256	C II

ISLANDS, ATLANTIC OCEAN.

BERMUDAS.

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Agar's Island, A*	32 17.6 N	295 12	Jan 10,'10	15.4	10 46.0 W			15.9, 16.8	.21061	2		C I
			Jan 11, 10	10.5, 12.4	10 44.5 W			11.1, 12.0	.21058	2		C I
			Jan 11, 10	13.9, 16.2, 16.7	10 46.0 W			14.5, 15.7	.21062	4		C I
			Jan 12, 10			10.4, 11.8	67 20.5 N				201.12	C I
Agar's Island, B*	32 17.6 N	295 12	Jan 10, 10			12.5	67 24.8 N				201.12	C I
			Jan 11, 10	10.6, 12.4	10 50.6 W			11.1, 12.0	.20960	4		C I
			Jan 11, 10	13.9, 16.2, 16.7	10 52.6 W					2		C I
			Jan 12, 10			13.7, 15.9	67 24.3 N				201.12	C I
			Jan 18, 10	9.9, 11.9 ...	10 47.4 W			10.5, 11.4	.20979	4		C I
Hunt's Island or Spectacle I*	32 15.9 N	295 10	Jan 22, 10	10.5	6 44.6 W	14.5, 16.3	64 56.8 N	11.3, 12.4	.23297	4	189.9,10	C I
Hunt's Island or Spectacle I, B*	32 15.9 N	295 10	Jan 22, 10	14.2, 16.5	6 46.3 W	10.6, 12.2	64 56.4 N	14.7, 15.7	.23291	4	189.9,10	C I

FALKLAND ISLANDS.

Station	Latitude	Long. East of Gr.	Date	Decl. L. M. T.	Decl. Value	Incl. L. M. T.	Incl. Value	H. I. L. M. T.	H. I. Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Port Stanley, A	51 41.2 S	302 10	Feb 3,'13	10.2, 12.4	10 11.2 E	14.2	45 46.7 S	10.9, 11.8	.26486	19	201.125	C II
Port Stanley, B	51 41.8 S	302 08	Feb 6, 13	9.6, 13.0	10 16.6 E			10.3, 11.1	.26472	19		C II
			Feb 6, 13					11.8, 12.5	.26486	19		C II
			Feb 10, 13	16.4, 17.4	10 14.8 E	11.3, 11.8	45 50.8 S			19	EI 2	C II
			Feb 10, 13			12.2, 12.5	45 51.2 S				EI 2	C II
			Feb 10, 13			12.8, 13.1	45 51.2 S				EI 2	C II
			Feb 10, 13			15.0, 15.4	45 51.0 S				EI 2	C II
			Feb 10, 13			15.6	45 51.0 S				EI 2	C II
			Feb 11, 13			11.9, 12.3	45 50.9 S				EI 2	C II
			Feb 11, 13			12.6, 15.7	45 50.8 S				EI 2	C II
			Feb 11, 13			16.1	45 50.4 S				EI 2	C II
			Feb 12, 13	15.4, 17.1	10 16.3 E	10.9, 11.6	45 53.7 S	15.9, 16.7	.26479	19	EI 3	C II
			Feb 12, 13			12.2, 12.9	45 52.8 S				EI 3	C II
			Feb 13, 13	10.2, 11.7	10 15.2 E			10.6, 11.3	.26450	19		C II
			Feb 13, 13	12.2, 14.8	10 18.7 E			12.5, 14.5	.26454	19		C II
			Feb 13, 13	15.4, 16.9	10 16.3 E			15.7, 16.5	.26478	2		C II
			Feb 14, 13	9.8, 11.5	10 16.8 E			10.3, 11.1	.26471	2		C II
			Feb 14, 13	12.0, 15.4	10 18.2 E			12.4, 14.9	.26474	2		C II
			Feb 17, 13	16.5, 19.0	10 14.6 E					19		C II
			Feb 20, 13	7.7, 9.3, 13.1	10 14.0 E			9.8, 10.7	.26456	19		C II
			Feb 20, 13					11.3, 12.7	.26453	19		C II
			Feb 20, 13					14.1	.26456	19		C II
Port Stanley, C	51 41.8 S	302 08	Feb 7, 13	10.9	10 16.2 E			11.4, 12.3	.26496	19		C II
			Feb 7, 13					14.2	.26507	19		C II
			Feb 8, 13			12.4, 12.9	45 51.9 S				EI 2	C II
			Feb 8, 13			14.7, 15.1	45 50.0 S				EI 2	C II
			Feb 8, 13			15.6, 16.1	45 50.7 S				EI 2	C II
			Feb 10, 13	6.7, 7.8	10 12.3 E					19		C II
			Feb 11, 13			12.0, 12.3	45 51.9 S				EI 3	C II
			Feb 11, 13			15.5, 16.0	45 52.0 S				EI 3	C II
			Feb 12, 13	15.4, 17.1	10 16.8 E	10.9, 11.7	45 52.8 S	15.9, 16.7	.26491	2	EI 2	C II
			Feb 12, 13			12.3, 12.8	45 52.4 S				EI 2	C II
			Feb 13, 13	10.2, 11.7	10 14.5 E			10.6, 11.3	.26460	2		C II
			Feb 13, 13	12.2, 14.8	10 17.2 E			12.5, 14.5	.26470	2		C II
			Feb 13, 13	15.4, 16.9	10 17.4 E			15.7, 16.5	.26460	19		C II
			Feb 14, 13	9.8, 11.5	10 15.8 E			10.3, 11.1	.26450	19		C II
			Feb 14, 13	12.0, 15.4	10 16.9 E			12.4, 14.9	.26462	19		C II
			Feb 18, 13	11.6, 17.7	10 14.8 E			12.8, 15.2	.26470	19		C II
			Feb 18, 13					15.9, 17.0	.26438	19		C II
			Feb 20, 13			13.9, 14.2	45 54.9 S				EI 3	C II
			Feb 20, 13			14.6, 14.9	45 54.4 S				EI 3	C II

ICELAND.

Station	Latitude	Long. East of Gr.	Date	Decl. L. M. T.	Decl. Value	Incl. L. M. T.	Incl. Value	H. I. L. M. T.	H. I. Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Akranes*	64 18.8 N	337 54	Sep 3,'14	11.5, 12.7	34 16.4 W	10.7, 11.0	75 36.6 N	11.8, 12.4	.13102	25	EI 25	C III
Kialarnes*	64 13.9 N	338 08	Sep 3, 14	15.7, 16.9	30 15.7 W	17.5, 17.7	76 06.0 N	16.0, 16.6	.12452	25	EI 25	C III
Reykjavik, A*	64 10.4 N	338 05	Aug 28, 14	8.9, 10.8	44 18.4 W			9.4, 10.4	.11675	5		C III
			Aug 28, 14	11.1, 13.0	44 24.2 W			11.5, 12.7	.11706	5		C III
			Aug 28, 14	13.9, 16.2	44 16.5 W			14.7, 15.9	.11738	5		C III

*Local disturbance.

ISLANDS, ATLANTIC OCEAN.

ICELAND—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Reykjavik, *A**—*Continued*	64 10.4 N	338 05	Aug 29,'14	8.4, 10.5	44 22.4 W			9.1, 10.1	.11654	25		C III
			Aug 29, 14	10.8, 12.7	44 23.0 W			11.1, 12.4	.11706	25		C III
			Aug 29, 14	13.0, 14.8	44 01.0 W			13.3, 14.3	.11831	25		C III
			Aug 30, 14			8.8 to 12.8	76 59.7 N	9.9, 10.7	.11686	25	EI 25	C III
			Aug 30, 14			14.3 to 16.9	76 51.0 N	13.2 to 16.2	.11793	25	EI 25	C III
			Sep 1, 14			9.0 to 10.8	76 59.2 N				EI 25	C III
			Sep 1, 14			11.5 to 13.6	76 58.7 N				EI 3	C III
			Sep 2, 14	8.5 to 16.2(9)	44 18.0 W			9.0 to 16.9	.11696	5		C III
			Sep 3, 14	8.1 to 17.2(9)	44 17.9 W			8.6 to 16.8	.11688	5		C III
			Sep 4, 14	8.2 to 15.0(5)	44 17.0 W			8.5 to 15.4	.11703	5		C III
			Sep 9, 14	11.5, 11.9	44 21.6 W					25		C III
			Sep 9, 14	12.8, 13.3	44 19.4 W					25		C III
			Sep 9, 14	14.0, 14.5, 15.0	44 14.5 W					5		C III
Reykjavik, *B**	64 10.4 N	338 05	Aug 26, 14	14.4	43 01 W					*189*		C III
			Sep 9, 14	11.4	43 03 W	11.4	77 20 N	11.4	*.1138*	*189*	189.7	C III
Reykjavik, *C**	64 10.4 N	338 05	Aug 26, 14	14.7, 15.1	42 14 W					*189*		C III
			Sep 9, 14	10.8	42 29 W	10.9	77 21 N	10.9	*.1133*	*189*	189.7	C III
Reykjavik, *D**	64 10.4 N	338 05	Aug 26, 14	15.4	44 37 W					*189*		C III
			Sep 9, 14	10.1	44 39 W	10.2	77 31 N	10.2	*.1146*	*189*	189.7	C III
Reykjavik, *E**	64 10.4 N	338 05	Aug 28, 14	8.9, 10.8	42 40.9 W			9.4, 10.4	.11862	25		C III
			Aug 28, 14	11.1, 13.0	42 46.3 W			11.4, 12.7	.11892	25		C III
			Aug 28, 14	13.9, 16.2	42 44.4 W			14.6, 15.8	.11924	25		C III
			Aug 29, 14	8.4, 10.5	42 44.2 W			9.0, 10.1	.11858	5		C III
			Aug 29, 14	10.8, 12.7	42 44.8 W			11.1, 12.5	.11888	5		C III
			Aug 29, 14	13.0, 14.8	42 24.6 W			13.3, 14.3	.12006	5		C III
			Aug 31, 14			8.6 to 15.6	76 53.4 N	9.4 to 15.0	.11883	25	EI 25	C III
			Sep 1, 14	14.1 to 19.0(dv)	42 34.3 W	9.0 to 10.8	76 53.8 N			25	EI 3	C III
			Sep 1, 14			11.5 to 13.6	76 53.5 N				EI 25	C III
			Sep 8, 14	8.3 to								
			Sep 9, 14	8.6(dv)	42 39.5 W					5		C III
			Sep 9, 14	11.5, 11.9	42 43.9 W					5		C III
			Sep 9, 14	12.8, 13.4	42 41.8 W					5		C III
			Sep 9, 14	14.0, 14.5, 15.0	42 37.3 W					25		C III
Videy Island*	64 10.4 N	338 08	Sep 9, 14	14.2	44 09 W	14.6	79 37 N	14.6	*.0928*	*189*	189.7	C III
Grotta*	64 09.7 N	337 59	Sep 2, 14	9.7, 11.1	35 23.0 W	11.9, 12.2	76 34.8 N	10.1, 10.8	.12236	25	EI 25	C III

MADEIRAS.

Station	Latitude	Long. East of Gr.	Date	Decl. Local Mean Time	Decl. Value	Incl. L. M. T.	Incl. Value	Hor. Int. L. M. T.	Hor. Int. Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Funchal, *A**	32 38 N	343 05	Nov 27,'09	14.2	20 24.9 W	15.3	53 52.2 N	15.4	*.25384*	*203*	203.56	C I
Funchal, *B**	32 38 N	343 05	Nov 27, 09	14.3	20 23.6 W	15.3	53 52.4 N	15.4	*.25260*	*201*	201.12	C I
Funchal, *C**	32 38 N	343 05	Nov 27, 09	10.4, 11.1	18 23.0 W	10.8	54 07.7 N			*203*	203.5	C I
Funchal, *D**	32 38 N	343 05	Nov 27, 09	10.4, 11.1	17 00.3 W	10.8	54 13.0 N			*201*	201.1	C I

ST. HELENA.

Station	Latitude	Long. East of Gr.	Date	Decl. Local Mean Time	Decl. Value	Incl. L. M. T.	Incl. Value	Hor. Int. L. M. T.	Hor. Int. Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Longwood, *A**	15 56.7 S	354 19	Apr 8,'13	11.4, 12.7	25 12.0 W			11.8, 12.4	.22126	19		C II
			Jun 26, 13	12.0, 14.3, 16.2	25 11.5 W			14.7, 15.6	.22080	4		C II
			Jun 27, 13	9.8, 12.0	25 11.4 W			10.4, 11.3	.22099	4		C II
			Jun 27, 13	12.9, 15.0	25 12.2 W			13.2, 14.3	.22097	4		C II
			Jun 27, 13	15.6, 17.4	25 09.4 W			16.0, 16.9	.22088	2		C II
			Jun 28, 13	9.9, 12.1	25 10.4 W			10.4, 11.3	.22122	2		C II
			Jun 28, 13	12.8, 14.6	25 09.4 W			13.2, 14.1	.22092	2		C II
			Jun 30, 13			11.9, 13.2	36 38.0 S				EI 2	C II
			Jun 30, 13			13.6, 14.2	36 38.5 S				EI 2	C II
			Jun 30, 13			14.6, 14.9	36 38.9 S				EI 2	C II
			Jun 30, 13			15.4, 15.7	36 38.8 S				EI 2	C II
			Jul 1, 13			11.1, 12.0	36 38.2 S				EI 2	C II
			Jul 1, 13			14.0, 14.7	36 39.2 S				EI 2	C II
			Jul 1, 13			15.1, 15.6	36 39.6 S				EI 2	C II

*Local disturbance.

ISLANDS, ATLANTIC OCEAN.

ST. HELENA—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Longwood, *A**—*Continued*	15 56.7 S	354 19	Jul 1, '13			16.0, 16.4	36 39.8 S				EI 2	C II
			Jul 2, 13	17.1, 17.6	25 11.2 W	10.5, 10.8	36 38.0 S			4	EI 3	C II
			Jul 2, 13			11.2, 11.4	36 37.6 S				EI 3	C II
			Jul 2, 13			11.6, 11.7	36 37.6 S				EI 3	C II
			Jul 2, 13			11.9, 12.1	36 39.9 S				EI 3	C II
			Jul 2, 13			13.4, 13.6	36 39.1 S				EI 3	C II
			Jul 2, 13			14.0, 14.1	36 39.2 S				EI 3	C II
			Jul 2, 13			14.3, 14.6	36 39.2 S				EI 3	C II
			Jul 2, 13			15.1, 15.4	36 39.8 S				EI 3	C II
			Jul 2, 13			15.8, 16.1	36 40.5 S				EI 3	C II
			Jul 2, 13			16.4	36 41.6 S				EI 3	C II
			Jul 7, 13	10.4, 12.3, 13.1	25 08.2 W			10.9, 11.8	.22092	2		C II
			Jul 7, 13	14.6, 15.0, 16.8	25 09.0 W			13.5, 14.2	.22102	2		C II
			Jul 7, 13					15.4, 16.3	.22072	2		C II
Longwood, *B**	15 56.7 S	354 19	Jun 30, 13			11.8, 12.3	36 45.7 S				EI 3	C II
			Jun 30, 13			13.2, 13.4	36 45.7 S				EI 3	C II
			Jun 30, 13			13.7, 13.9	36 46.9 S				EI 3	C II
			Jun 30, 13			14.2, 14.4	36 46.6 S				EI 3	C II
			Jun 30, 13			14.8, 15.0	36 47.3 S				EI 3	C II
			Jun 30, 13			15.4, 15.6	36 47.0 S				EI 3	C II
			Jun 30, 13			15.9	36 48.2 S				EI 3	C II
			Jul 3, 13	10.0, 11.5, 12.5	24 43.8 W			10.4, 11.2	.22072	4		C II
			Jul 3, 13	13.5, 13.9, 15.0	24 43.6 W			12.8, 13.3	.22070	4		C II
			Jul 3, 13					14.2, 14.7	.22068	4		C II
			Jul 3, 13					15.6	.22059	4		C II
			Jul 7, 13	10.4, 12.3, 13.1	24 41.7 W			10.9, 11.8	.22077	4		C II
			Jul 7, 13	14.6, 15.0, 16.8	24 42.3 W			13.5, 14.2	.22064	4		C II
			Jul 7, 13					15.4, 16.3	.22042	4		C II
			Jul 15, 13	10.2, 11.8	24 42.8 W					4		C II
Longwood, *C**	15 56.7 S	354 19	Jun 26, 13	12.0, 14.3, 16.2	25 03.2 W			13.0, 14.7	.21555	2		C II
			Jun 26, 13					15.6	.21550	2		C II
			Jun 27, 13	9.8, 12.0	25 03.6 W			10.4, 11.3	.21573	2		C II
			Jun 27, 13	12.9, 15.0	25 04.6 W			13.3, 14.3	.21568	2		C II
			Jun 27, 13	15.6, 17.4	25 04.8 W			16.0, 16.9	.21534	4		C II
			Jun 28, 13	9.9, 12.1, 12.8	25 05.9 W			10.4, 11.3	.21588	4		C II
			Jun 28, 13	14.6, 16.8, 17.4	25 04.7 W			13.2, 14.2	.21557	4		C II
			Jul 1, 13			10.5, 10.9	37 36.8 S				EI 3	C II
			Jul 1, 13			11.2, 11.5	37 36.9 S				EI 3	C II
			Jul 1, 13			11.8, 12.0	37 36.1 S				EI 3	C II
			Jul 1, 13			12.2, 12.4	37 37.3 S				EI 3	C II
			Jul 1, 13			13.8, 14.4	37 36.9 S				EI 3	C II
			Jul 1, 13			14.8, 15.2	37 36.8 S				EI 3	C II
			Jul 1, 13			15.6, 15.8	37 37.5 S				EI 3	C II
			Jul 1, 13			16.2	37 37.3 S				EI 3	C II
			Jul 2, 13			11.5, 12.0	37 34.5 S				EI 2	C II
			Jul 2, 13			12.3, 12.6	37 36.2 S				EI 2	C II
			Jul 2, 13			13.3, 13.8	37 36.8 S				EI 2	C II
			Jul 2, 13			14.1, 14.4	37 37.0 S				EI 2	C II
			Jul 2, 13			15.2, 15.6	37 37.6 S				EI 2	C II
Longwood, *D**	15 56.7 S	354 20	Jul 8, 13	15.4, 17.4	26 07.2 W			15.9, 17.0	.22805	4		C II
			Jul 15, 13			10.3, 10.8	35 25.6 S				201.12	C II

WEST INDIES.

Station	Latitude	Long. East of Gr.	Date	Decl. L. M. T.	Decl. Value	Incl. L. M. T.	Incl. Value	H. I. L. M. T.	H. I. Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Culebra I., Scorpion Point	18 18.2 N	294 41	Aug 6, '10	10.2, 12.7	2 54.1 W	13.9, 17.1	50 26.7 N	10.7, 12.3	.28436	4	201.12	C II
Vieques, *New Absolute Observatory*	18 08.8 N	294 33	Jul 26, 10			10.9, 11.6	49 53.8 N				201.12	C II
			Jul 26, 10			14.2	49 54.1 N				201.12	C II
			Jul 29, 10	10.0, 14.2, 16.2	2 22.0 W			11.0, 15.2	.28822	4		C II
			Jul 30, 10	9.6, 11.4	2 20.4 W			10.2, 10.9	.28816	2		C II
			Jul 30, 10	13.4, 15.0	2 23.1 W			13.8, 14.5	.28835	2		C II
Vieques, *1*	18 08.8 N	294 33	Jul 27, 10			10.3, 10.9	50 00.0 N				201.12	C II

*Local disturbance.

ISLANDS, ATLANTIC OCEAN.

WEST INDIES—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Vieques, *1—Continued*	18 08.8 N	294 28	Jul 27,'10			11.6	50 08.8 N				201.12	C II
			Jul 28, 10	9.9, 11.8	2 24.2 W			10.6, 11.4	.28068	2		C II
			Jul 28, 10	13.7, 15.4	2 25.2 W			14.2, 15.8	.28081	2		C II
			Jul 30, 10	9.6, 11.4	2 22.5 W			10.6	.28794	4		C II
			Jul 30, 10	13.3, 15.0	2 24.7 W			14.2	.28783	4		C II
Vieques, *2*	18 08.8 N	294 28	Jul 28, 10	9.9, 11.9	2 24.1 W			10.6, 11.4	.28780	4		C II
			Jul 28, 10	13.7, 15.4	2 24.8 W			14.8	.28767	4		C II
			Jul 29, 10	10.0, 11.9	2 22.0 W			10.6, 11.4	.28788	2		C II
			Jul 29, 10	14.2, 16.2	2 24.2 W			14.8, 15.6	.28780	2		C II

ISLANDS, INDIAN OCEAN.

CEYLON.

Station	Latitude	Long. East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c.g.s.			
Colombo, *Cinnamon Gardens*	6 55.1 N	79 52	Sep 12,'11	12.7, 14.6	2 02.2 W			12.2, 14.2	.37874	4		C II
			Sep 13, 11			10.7	4 37.5 S				201.206	C II
Colombo, *A*	6 54.2 N	79 52	Jun 13, 11	10.6, 14.2, 14.7	1 36.4 W			11.4, 13.8	.37981	4		C II
			Jun 13, 11					15.2, 16.2	.37980	4		C II
			Jun 14, 11	9.8, 10.0	1 34.6 W			10.7, 11.5	.38022	4		C II
			Jun 14, 11	10.2, 11.9	1 34.4 W					4		C II
			Jun 14, 11	13.7, 16.6	1 35.6 W			14.2, 16.0	.37981	2		C II
			Jun 15, 11	10.1, 12.5	1 35.6 W			10.8, 12.0	.37982	2		C II
			Jun 15, 11	13.6, 15.8	1 34.7 W			14.1, 15.3	.38030	2		C II
			Jun 16, 11	8.2, 9.8, 10.0	1 34.1 W			8.6, 9.5	.38081	2		C II
			Jun 16, 11	13.6, 13.8, 15.6	1 36.3 W			10.2, 13.2	.37986	2		C II
			Jun 16, 11	16.9, 17.2	1 34.2 W			14.2, 15.2	.38016	2		C II
			Jun 17, 11			10.8, 11.4	4 36.6 S				EI 2	C II
			Jun 17, 11			12.3	4 37.7 S				EI 2	C II
			Jun 19, 11	10.0, 10.3	1 36.8 W	12.5, 13.2	4 36.4 S			2	201.12	C II
			Jun 19, 11	10.4, 10.7	1 37.0 W	13.8, 14.5	4 36.7 S			2	201.12	C II
			Jun 27, 11	9.8, 11.2	1 35.6 W			10.5, 13.2	.38080	2		C II
			Jun 27, 11	12.6, 13.9	1 37.4 W					2		C II
			Jun 29, 11			11.0, 11.8	4 37.0 S				EI 2	C II
			Jun 29, 11			12.2, 12.7	4 37.3 S				EI 2	C II
			Jun 29, 11			13.1, 15.3	4 38.2 S				EI 2	C II
			Jun 29, 11			16.1, 17.0	4 39.0 S				EI 2	C II
			Jun 29, 11			17.5	4 39.3 S				EI 2	C II
Colombo, *B*	6 54.2 N	79 52	Jun 16, 11	8.2, 9.8, 10.1	1 30.8 W			8.6, 9.5	.38202	4		C II
			Jun 16, 11	13.6, 13.8, 15.6	1 32.6 W			10.4, 13.2	.38198	4		C II
			Jun 16, 11					14.2, 15.2	.38184	4		C II
			Jun 19, 11			12.1, 12.6	4 35.0 S				EI 2	C II
			Jun 19, 11			13.5, 14.0	4 35.4 S				EI 2	C II
			Jun 19, 11			14.8	4 36.7 S				EI 2	C II
			Jun 20, 11			9.8, 10.6	4 33.6 S				EI 2	C II
			Jun 20, 11			11.3, 12.7	4 35.7 S				EI 2	C II
			Jun 20, 11			13.2, 14.0	4 36.8 S				EI 2	C II
			Jun 20, 11			14.8, 15.8	4 38.4 S				EI 2	C II
			Jun 21, 11			11.0, 11.8	4 36.6 S				EI 2	C II
			Jun 21, 11			12.2, 13.6	4 37.6 S				EI 2	C II
			Jun 21, 11			14.0, 14.6	4 37.5 S				EI 2	C II
			Jun 21, 11			15.1, 15.6	4 36.6 S				EI 2	C II
			Jun 27, 11	14.5, 16.0, 17.4	1 32.1 W			15.2, 16.9	.38206	2		C II
Colombo, *C*	6 54.2 N	79 52	Jun 13, 11	10.5, 14.3, 14.7	1 34.6 W			11.5, 13.8	.37997	2		C II
			Jun 13, 11					15.3, 16.3	.37999	2		C II
			Jun 14, 11	9.8, 10.0	1 35.6 W			10.7, 11.5	.38052	2		C II
			Jun 14, 11	10.3, 11.9	1 35.8 W					2		C II
			Jun 14, 11	13.7, 16.6	1 35.6 W			14.4, 15.9	.38000	4		C II
			Jun 15, 11	10.1, 12.5	1 36.2 W			10.8, 12.1	.38020	4		C II
			Jun 15, 11	13.6, 15.8	1 35.2 W			14.1, 15.4	.38026	4		C II

ISLANDS, INDIAN OCEAN.

JAVA.

Station	Latitude	Long. East of Gr.	Date	Declination		Inclination		Hor. Intensity		Instruments		Obs'r
				Local Mean Time	Value	L. M. T.	Value	L. M. T.	Value	Mag'r	Dip Circle	
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Weltevreden (Batavia), *A*	6 11.0 S	106 50	Nov 1,'11			10.8, 11.5	31 17.0 S				EI 2	C II
			Nov 1, 11			15.2, 15.8	31 20.0 S				EI 2	C II
			Nov 1, 11			16.4, 17.0	31 20.4 S				EI 2	C II
			Nov 4, 11	8.7, 11.3, 14.3	0 41.6 E			9.3, 10.8	.36700	4		C II
			Nov 4, 11	15.7, 17.0	0 41.7 E			14.8, 16.4	.36702	4		C II
			Nov 10, 11	15.8, 16.1, 16.4	0 45.0 E					4		C II
Weltevreden (Batavia), *B*	6 11.0 S	106 50	Nov 2, 11			8.7, 9.6	31 19.0 S				EI 2	C II
			Nov 2, 11			10.2, 10.7	31 18.5 S				EI 2	C II
			Nov 2, 11			11.1, 12.0	31 18.2 S				EI 2	C II
			Nov 2, 11			12.6	31 18.0 S				EI 2	C II
			Nov 3, 11	7.3, 8.5, 8.9	0 42.3 E			7.8, 9.6	.36738	4		C II
			Nov 3, 11	10.0, 10.3, 12.4	0 45.0 E			10.7, 12.1	.36718	4		C II
			Nov 7, 11	7.1	0 45.7 E					4		C II
Weltevreden (Batavia), *Pier A*	6 11.0 S	106 50	Nov 7, 11					20.0, 21.4	.36708	4		C II
			Nov 8, 11					20.5	.36717	4		C II
Weltevreden (Batavia), *Pier C*	6 11.0 S	106 50	Oct 30, 11					19.7, 21.2	.36735	4		C II
			Oct 31, 11					19.5, 20.6	.36727	4		C II
Weltevreden (Batavia), *Declination Pier*	6 11.0 S	106 50	Nov 2, 11	20.9, 22.1	0 47.6 E					4		C II
			Nov 3, 11	20.4, 20.5	0 47.8 E					4		C II
			Nov 3, 11	20.9, 21.1	0 47.0 E					4		C II
Weltevreden (Batavia), *Earth-Inductor Pier*	6 11.0 S	106 50	Nov 4, 11			21.4, 22.1	31 19.5 S				EI 2	C II
			Nov 10, 11			19.4, 19.9	31 20.0 S				EI 2	C II
			Nov 13, 11			21.0, 21.6	31 21.2 S				EI 2	C II
			Nov 13, 11			23.6, 24.1	31 20.1 S				EI 2	C II

MAURITIUS.

Station	Latitude	Long. East of Gr.	Date	Declination LMT	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value	Mag'r	Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Pamplemousses, *A**	20 05.6 S	57 34	Aug 12,'11	8.8, 11.8, 12.3	9 23.9 W			9.5, 10.2	.23317	4		C II
			Aug 12, 11					10.8, 11.4	.23318	4		C II
Pamplemousses, *B**	20 05.6 S	57 34	Aug 8, 11	14.9, 16.5	8 38.5 W			15.7	.23129	4		C II
			Aug 9, 11	8.9, 10.0	8 42.8 W			9.6, 10.9	.23143	4		C II
			Aug 9, 11	10.4, 11.4	8 45.0 W					4		C II
			Aug 10, 11	9.2	8 41.3 W			9.8, 10.3	.23148	4		C II
			Aug 14, 11			10.6, 11.0	54 27.6 S				EI 2	C II
			Aug 14, 11			11.6, 12.2	54 27.8 S				EI 2	C II
			Aug 14, 11			14.9, 15.4	54 26.9 S				EI 2	C II
			Aug 14, 11			16.3, 17.0	54 27.7 S				EI 2	C II
			Aug 15, 11			7.6, 8.2	54 27.2 S				EI 2	C II
			Aug 15, 11			9.6, 10.1	54 27.4 S				EI 2	C II
			Aug 15, 11			10.6, 11.1	54 27.0 S				EI 2	C II
			Aug 15, 11			11.4, 12.5	54 26.7 S				EI 2	C II
			Aug 15, 11			12.9, 13.3	54 27.0 S				EI 2	C II
			Aug 15, 11			15.1, 15.8	54 27.0 S				EI 2	C II
Pamplemousses, *C**	20 05.6 S	57 34	Aug 9, 11	14.5, 16.3, 16.5	9 49.9 W			15.1, 15.9	.23530	4		C II
			Aug 9, 11					16.9	.23522	4		C II
			Aug 10, 11					11.3, 12.0	.23528	4		C II
			Aug 10, 11					15.7	.23519	4		C II
Pamplemousses, *D**	20 05.6 S	57 34	Aug 11, 11			9.4, 10.0	53 24.8 S				EI 2	C II
			Aug 11, 11			10.5, 11.1	53 24.5 S				EI 2	C II
			Aug 11, 11			11.5, 11.9	53 23.9 S				EI 2	C II
			Aug 11, 11			14.7, 15.2	53 22.7 S				EI 2	C II
			Aug 11, 11			15.7, 15.9	53 23.3 S				EI 2	C II
			Aug 12, 11			14.8, 15.2	53 22.2 S				EI 2	C II
			Aug 12, 11			15.6, 15.9	53 23.4 S				EI 2	C II

*Local disturbance.

ISLANDS, PACIFIC OCEAN.

FIJI ISLANDS.

Station	Latitude	Long. East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Suva Vou, *A*	18 07.1 S	178 25	Jun 13,'12	10.3, 12.8	10 22.8 E			10.8, 12.2	.34734	4		C II
			Jun 13, 12	13.9, 16.1	10 24.6 E			14.3, 15.5	.34705	4		C II
			Jun 14, 12	10.6, 13.8	10 22.9 E			11.3, 13.4	.34731	2		C II
			Jun 14, 12	14.2, 16.0	10 23.6 E			14.6, 15.5	.34708	2		C II
			Jun 19, 12			10.3, 11.0	38 27.8 S				EI 2	C II
			Jun 19, 12			11.5, 12.0	38 28.4 S				EI 2	C II
			Jun 19, 12			13.4, 14.3	38 28.0 S				EI 2	C II
			Jun 19, 12			15.0, 15.6	38 27.9 S				EI 2	C II
Suva Vou, *B*	18 07.1 S	178 25	Jun 11, 12	14.6, 16.4	10 26.5 E			15.3	.34652	2		C II
			Jun 12, 12	10.7, 12.0, 12.9	10 23.7 E			11.2, 13.4	.34677	2		C II
			Jun 12, 12	14.3, 15.7	10 26.2 E			15.0	.34669	2		C II
			Jun 12, 12	16.0, 17.1	10 26.4 E					2		C II
			Jun 13, 12	10.3, 12.8	10 25.0 E			10.8, 12.3	.34672	2		C II
			Jun 13, 12	13.9, 16.1	10 25.4 E			14.4, 15.6	.34654	2		C II
			Jun 14, 12	10.6, 13.8	10 24.8 E			11.3, 13.3	.34666	4		C II
			Jun 14, 12	14.2, 16.0	10 24.8 E			14.6, 15.5	.34683	4		C II
			Jun 15, 12	10.3, 10.6, 10.9	10 24.2 E					4		C II
			Jun 15, 12	11.2, 11.9	10 24.2 E					4		C II
			Jun 17, 12			13.0, 13.4	38 28.8 S				EI 2	C II
			Jun 17, 12			13.9, 14.3	38 28.8 S				EI 2	C II
			Jun 17, 12			14.7, 15.1	38 28.6 S				EI 2	C II
			Jun 17, 12			15.6	38 28.7 S				EI 2	C II
			Jun 18, 12			10.1, 10.6	38 27.6 S				EI 2	C II
			Jun 18, 12			11.1, 11.8	38 28.0 S				EI 2	C II
			Jun 18, 12			14.6, 15.1	38 28.8 S				EI 2	C II

PHILIPPINE ISLANDS.

Station	Latitude	Long. East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Antipolo, *A*	14 35.9 N	121 11	Feb 14,'12			8.6, 9.0	16 17.7 N				EI 2	C II
			Feb 14, 12			9.5, 10.0	16 16.8 N				EI 2	C II
			Feb 14, 12			11.0, 11.6	16 15.8 N				EI 2	C II
			Feb 14, 12			12.0, 14.1	16 16.7 N				EI 2	C II
			Feb 14, 12			14.6, 14.9	16 17.5 N				EI 2	C II
			Feb 14, 12			15.3, 15.6	16 18.0 N				EI 2	C II
			Feb 17, 12	9.2	0 38.7 E			9.9	.38211	4		C II
			Feb 19, 12	14.1, 16.2	0 39.4 E			14.7, 15.8	.38203	4		C II
			Feb 19, 12	17.6, 17.8	0 39.8 E					4		C II
			Feb 20, 12	9.0, 10.5	0 38.6 E			9.6	.38225	4		C II
			Feb 20, 12	11.0, 11.3	0 37.9 E					4		C II
Antipolo, *B*	14 35.9 N	121 11	Feb 8, 12	14.8, 16.3	0 43.4 E			15.5	.38193	4		C II
			Feb 9, 12	9.8, 11.0, 11.3	0 40.9 E			10.3, 11.9	.38218	4		C II
			Feb 9, 12	13.8, 15.2	0 42.2 E			14.6	.38183	4		C II
			Feb 10, 12	7.3, 7.8	0 42.9 E					4		C II
			Feb 15, 12			14.3, 15.0	16 08.6 N				EI 2	C II
			Feb 15, 12			15.4, 16.1	16 08.9 N				EI 2	C II
			Feb 15, 12			16.6, 17.1	16 08.9 N				EI 2	C II
			Feb 16, 12			8.9, 10.4	16 07.8 N				EI 2	C II
			Feb 20, 12	12.0, 14.2, 14.4	0 41.4 E	16.2, 17.0	16 09.3 N			4	EI 2	C II
			Feb 20, 12			17.7	16 10.5 N				EI 2	C II
			Feb 22, 12	6.8, 7.0, 7.3	0 41.8 E					4		C II
			Feb 22, 12	7.6, 7.9, 8.1	0 41.5 E					4		C II
Antipolo, *C*	14 35.9 N	121 11	Feb 10, 12	9.0, 10.5, 11.8	0 39.5 E			9.7	.38227	4		C II
			Feb 10, 12					11.3, 12.2	.38220	4		C II
			Feb 12, 12	11.7, 12.1, 14.6	0 39.3 E			14.1	.38224	4		C II
			Feb 13, 12			11.0, 11.8	16 11.2 N				EI 2	C II
			Feb 13, 12			14.3, 15.0	16 12.6 N				EI 2	C II
			Feb 13, 12			15.6, 16.0	16 13.0 N				EI 2	C II
			Feb 13, 12			16.5	16 13.8 N				EI 2	C II
			Feb 22, 12	10.6, 10.9, 11.1	0 38.9 E					4		C II

ISLANDS, PACIFIC OCEAN.

SOCIETY ISLANDS.

Station	Latitude	Long. East of Gr.	Date	Declination: Local Mean Time	Declination: Value	Inclination: L. M. T.	Inclination: Value	Hor. Intensity: L. M. T.	Hor. Intensity: Value	Instruments: Mag'r	Instruments: Dip Circle	Obs'r
	° ′	° ′		h h h	° ′	h h	° ′	h h	c. g. s.			
Papeete*.	17 31.8 S	210 27	Sep 27,'12			14.8	30 00.7 S				201.125	C II
			Sep 28, 12	9.8, 11.6	8 21.5 E			10.4, 11.2	.33448	4		C II
Small Coral Island (Papeete Harbor), *A**.	17 33.0 S	210 25	Sep 20, 12			10.2, 11.0	29 39.3 S				EI 2	C II
			Sep 20, 12			12.6, 13.1	29 37.6 S				EI 2	C II
			Sep 20, 12			13.8, 14.5	29 37.3 S				EI 2	C II
			Sep 20, 12			15.1	29 38.0 S				EI 2	C II
			Sep 23, 12	9.0, 10.6, 10.8	9 58.6 E			9.8, 11.4	.33834	2		C II
			Sep 23, 12	12.1, 13.3, 14.5	10 01.5 E			13.9	.33810	2		C II
			Sep 23, 12	16.6, 17.8	10 02.4 E					2		C II
			Sep 24. 12	9.6, 11.6, 12.8	9 58.9 E			10.1, 11.3	.33831	4		C II
			Sep 24, 12	14.5, 15.1, 16.6	9 59.8 E			13.2, 14.1	.33809	4		C II
			Sep 24, 12					15.5, 16.3	.33820	4		C II
			Sep 25, 12	9.4, 11.2, 11.4	9 57.7 E			9.8, 10.8	.33821	2		C II
			Sep 25, 12	13.6, 13.8, 15.6	10 00.6 E			11.7, 13.2	.33800	2		C II
			Sep 25, 12					14.2, 15.2	.33808	2		C II
			Oct 3, 12	9.3, 11.4, 12.2	9 58.1 E			9.9, 10.9	.33854	19		C II
			Oct 3, 12	13.6, 13.9, 15.3	10 00.8 E			12.6, 13.3	.33857	19		C II
			Oct 3, 12					14.2, 14.9	.33854	19		C II
			Oct 4, 12			11.0, 11.6	29 36.4 S				EI 2	C II
			Oct 4, 12			13.3, 13.7	29 36.9 S				EI 2	C II
			Oct 4, 12			14.7, 15.4	29 38.0 S				EI 2	C II
			Oct 4, 12			16.0	29 38.8 S				EI 2	C II
			Oct 10, 12	0.5	9 58.7 E					19		C II
			Oct 10, 12	1.0 to 6.0(dv)	9 59.3 E					19		C II
			Oct 10, 12	6.1	9 59.2 E					19		C II
Small Coral Island (Papeete Harbor), *B**.	17 33.0 S	210 25	Sep 19, 12			10.6, 11.2	29 38.9 S				EI 2	C II
			Sep 19, 12			11.6, 12.8	29 37.7 S				EI 2	C II
			Sep 19, 12			14.1, 14.6	29 36.6 S				EI 2	C II
			Sep 19, 12			15.4, 16.0	29 37.3 S				EI 2	C II
			Sep 21, 12	9.7, 11.1, 11.3	10 01.1 E			10.3, 12.5	.33890	2		C II
			Sep 21, 12	13.2, 13.4, 14.9	10 04.6 E			14.1	.33863	2		C II
			Sep 24, 12	9.6, 11.6, 12.8	10 05.0 E			10.1, 11.3	.33858	2		C II
			Sep 24, 12	14.5, 15.1, 16.6	10 06.4 E			13.2, 14.2	.33840	2		C II
			Sep 24, 12					15.5, 16.3	.33850	2		C II
			Sep 25, 12	9.4, 11.2, 11.4	10 02.3 E			9.9, 10.8	.33892	4		C II
			Sep 25, 12	13.6, 13.8, 15.6	10 04.3 E			11.7, 13.2	.33880	4		C II
			Sep 25, 12	16.3, 17.6	10 04.1 E					2		C II
			Sep 25, 12					14.1, 15.2	.33876	4		C II
			Sep 26, 12	9.3, 10.8	10 01.7 E					2		C II
			Oct 3, 12	9.3, 11.4, 12.2	10 01.8 E			9.8, 11.0	.33901	4		C II
			Oct 3, 12	13.6, 13.9, 15.3	10 04.9 E			12.5, 13.3	.33918	4		C II
			Oct 3, 12					14.2, 15.0	.33898	4		C II
			Oct 5, 12			9.9, 10.5	29 37.6 S				EI 2	C II
			Oct 5, 12			11.0, 11.4	29 36.8 S				EI 2	C II
			Oct 5, 12			11.8, 13.2	29 36.9 S				EI 2	C II
			Oct 5, 12			13.5, 14.2	29 37.2 S				EI 2	C II
			Oct 5, 12			14.5, 15.0	29 37.6 S				EI 2	C II
			Oct 5, 12			15.5	29 38.2 S				EI 2	C II

*Local disturbance.

DESCRIPTIONS OF SHORE STATIONS, 1909-1914.

One of the chief difficulties experienced by the observers of the Department of Terrestrial Magnetism in the reoccupation of old stations for secular-variation data has been the lack of information necessary to precise recovery of the point where the previous observations were made. Owing to the frequent occurrence of local disturbances, it may readily happen that erroneous secular-variation data will result from non-recovery of exact station. Accordingly the observers of the Department are instructed to furnish as complete descriptions as possible of stations occupied, especially of such as give promise of future availability. Information additional to that contained in the published descriptions or copies of station-sketches or of photographs of surroundings will gladly be supplied to those interested in the reoccupation of any of the stations.

The descriptions are given in alphabetical order under the same geographical divisions adopted in the preceding Table of Shore Results. The general form followed in the descriptions is: name of station, year when occupied, general location, detailed location, distances and references to surrounding objects, manner of marking, and finally the true bearings of prominent objects likely to be of permanent character. All bearings, unless specifically stated otherwise, are true ones, and are reckoned continuously from 0° to 360°, in the direction south, west, north, east. When no mention is made of marking of station, it is to be understood that the station was either not marked at all or not in a permanent manner.

Most of the measured distances were made originally in the English system; however, the distances obtained by conversion into the metric system are also given, but inclosed in parentheses, so as to show that they are converted figures. The following rules have been adopted in the conversions: distances given to 0.01 foot are converted to the nearest 0.001 meter, 0.1 foot to the nearest 0.01 meter, 1 foot to the nearest 0.1 meter, estimated feet or yards to nearest meter, estimated fraction of a mile to nearest 0.1 kilometer, and estimations of more than a mile to nearest kilometer. Short and important reference distances, when measured accurately, have been converted into nearest 0.1 centimeter; such measurements, however, as, for example, dimensions of marking-stones, etc., which are not of great importance, have been converted to the nearest centimeter. If a distance is given immediately preceding an azimuth of a mark, it is to be interpreted as distance from the magnetic station to the mark.

AFRICA.

British South and Central Africa.

Cape Town, Cape Colony, 1911.—Four stations, *A*, *B*, *C*, and *D*, all in line with bottom of weather vane on hospital tower, were established in field belonging to the Valkenberg Mental Hospital; the field is back of North Lodge and bounded on north and west by Royal Astronomical Observatory, with avenue along western boundary leading to hospital. Main station, *A*, is one-third kilometer northwest of hospital, 273 feet (83.2 meters) from fence bounding avenue to westward, and same distance from fence bounding field to southward; marked by wood post projecting about 2 feet 6 inches (76 cm.) above ground, center of post marking exact point. True bearings: triangulation mark on Devil's Peak, 3 kilometers, 60° 06′.9; gable of lodge, 127° 08′.6; bottom of weather vane on hospital tower, 318° 11′.8. *B* is 98.4 feet (29.99 meters) nearer hospital than *A*. *C* is 90.7 feet (27.65 meters) farther from hospital than *A*. *D* is 181.6 feet (55.35 meters) farther from hospital than *A*.

EUROPE.

Great Britain.

Falmouth, England, 1909, 1913.—Three stations, designated *A*, *B*, and *C*, were occupied in 1913, *A* and *B* being reoccupations of 1909 stations. Main station *A* is on flat forming Trefusis Point, 11 meters from edge of bush on bank, 41.6 meters from southeast post of football goal, and 37.6 meters from northwest post of goal; marked by cross in top of Oregon pine post sunk flush with ground. True bearings: sharp church spire on hilltop, 43° 29′.3; center of St. Anthony Lighthouse tower, 308° 50′.0; main flagpole on Pendennis Castle, 339° 52′.1. *B* is 20.15 meters northwest of *A*, on azimuth line produced from St. Anthony Lighthouse tower, and 29.0 meters from northwest post of football goal. *C* is 28.40 meters northeast of *A*, on azimuth line produced from church spire on hilltop.

Falmouth Observatory, England, 1909, 1913.—Observations were made at Falmouth Observatory on brick pier in the hut used for absolute observations, and used in

NORTH AMERICA.

UNITED STATES—*concluded.*

Greenport, Long Island, New York, 1909, 1910, 1913, 1914—continued.
with United States Coast and Geodetic Survey station of 1904. It is in northern part of school grounds just south of row of large maple trees; marked by marble post lettered on top "U.S.C.& G.S. 1904," with hole at center marking precise point. Presbyterian Church spire is in true bearing 203° 22′.2. Station *B* is 52.7 feet (16.06 meters) from station *A* in line from *A* to spire of Catholic Church. Catholic Church spire is in true bearing 45° 27′.4.

New York (Bronx Park), New York, 1909, 1910.—Station *A* in Botanical Gardens of Bronx Park, east of Botanical Museum and east of the Bronx River, at the highest point, and near center of open space southeast of stone hut. The southwest corner of stone hut is distant 193.6 feet (59.02 meters), a lamp-post on the west side of park road is 74.6 feet (22.73 meters) to the east-northeast, and a second lamp-post is 93.2 feet (28.41 meters) to the southeast on the east side of park road. The station of the U. S. Coast and Geodetic Survey is distant 129.5 feet (39.45 meters) to the west. The station is marked by a heavy wedge about 16 inches (40 cm.) long, projecting about 4 inches (10 cm.) above the general surface. True bearings: flagpole on police station, 128° 37′.0; southwest corner of stone hut, 166° 33′.8. An auxiliary station, *B*, was established on the line joining the main station with flagpole on police station of Precinct No. 79, produced northwestwardly 67.3 feet (20.5 meters). This point is about 2½ feet (0.8 meter) lower than the principal station and on the edge of a small bluff.

SOUTH AMERICA.

ARGENTINA.

Buenos Aires, Victoria, 1911.—Observations were made to northwest of Victoria Cemetery about 200 meters north of station of Argentine Meteorological Office.

Pilar, Cordoba, 1911.—Four stations, *Pier 1*, *Pier 8*, station *B*, and station *C*, were established at the Magnetic Observatory; all in line with observatory mark No. 1 (black line painted on stone pier) which is in true bearing 100° 14′.6. *Pier 1*, in absolute house, is 139.2 meters east of mark No. 1, and is observatory station for absolute determinations of declination and horizontal intensity. *Pier 8*, in absolute house, is 9.02 meters east of *Pier 1*, and is observatory station for absolute determinations of inclination. *B* is 33.04 meters east of *Pier 8* in line to mark No. 1 extended; marked by pier erected by observatory authorities. *C* is 28.1 meters east of *B* in line to mark No. 1 extended; marked by pier erected by observatory authorities.

BRAZIL.

Jaburu, Bahia, 1913.—Three stations, designated *A*, *B*, and *C*, were occupied on Itaparica Island west of Bahia and south of small pier at brick works, between shore and road. *A* is on beach 65.2 meters south of south rail of narrow-gage railway running from brick works to pier, 4.6 meters from well-defined shore line, 6.6 meters from nearest of three coconut trees to northwest, and 16.6 meters east of wire fence. True bearings: dome of prominent cathedral in Bahia, 285° 40′.7; tip on San Antonio Lighthouse, 308° 10′.8; right-hand tip of white cornice on ruins, 353° 28′.4. Primary station *B* is on line from *A* to white cornice on ruins, 30.43 meters from *A*, 5.0 meters from shore line, 14.1 meters from fence on west side of road; marked by tarred post, 4 feet (1.2 meters) long, and 3 by 5 inches (8 by 13 cm.) on top, lettered "C.I.W." on south, and "1913" on north side, with cross near southwest corner of top to mark precise position, and set so as to project about 6 inches (15 cm.) above surface. True bearings: north edge of round tower on hill above station, 82° 42′.9; church spire north of Bahia, 247° 24′.4; dome of prominent cathedral in Bahia, 285° 30′.8; tip on San Antonio Lighthouse, 308° 03′.1; right-hand tip of white cornice on ruins, 353° 28′.4. *C* is in line with stations *A* and *B*, 32.30 meters south of *B*, 4.6 meters from the shore line, 4.85 meters and 9.57 meters from coconut trees to northeast and southwest respectively, and 9.72 meters from evergreen tree to southeast; marked by peg with cross cut in top. True bearings: tip on San Antonio Lighthouse, 307° 55′.1; right-hand tip of white cornice on ruins, 353° 28′.4.

Pernambuco, Pernambuco, 1913.—The United States Coast and Geodetic Survey station of 1907 was found obliterated by cutting away by ocean of shore of Isthmus of Olinda. New station is within 150 yards (137 meters) of 1907 station and about midway between cable house and Port Buraco, but slightly nearer latter, 12 feet (3.7 meters) inland from ridge along sea side of isthmus; marked by 3 large wooden tripod pegs. True bearings: center of dome of Arsenal Marinha, 6° 19′.6; cross on old monument near cable house, 16° 11′.8; tallest yellow spire of church, 25° 48′.2; red dome of Assembly Hall, 35° 59′.7; chimney of Beltrao Sugar Refinery, 158° 36′.5; Picão Lighthouse, 341° 14′.0.

Pinheiro, Para, 1910.—Three stations, *A*, *B*, and *C*, were occupied at this point. The stations are situated in the town of Pinheiro on the east bank of the Para River and about 10 miles (16 kilometers) north of the city of Para. Station *A* is the same as the Brazilian station of 1903. It is on the point of land directly in front of the São Sebastião Church and 69.5 meters from its southwest corner; it is about 100 meters in the direction northeast from end of government wharf and about 10 meters from edge of steep river embankment. This station is marked by concrete blocks 28 cm. square by 4½ cm. thick built up to a height of 76 cm. On the top block there is a copper plate bearing the date of the Brazilian observations, name of the observer, latitude, longitude, and magnetic elements at the time of observation. The exact point is at the edge of copper plate directly over second "R" in the word "DIRECTORIA"; this point is 8.9 cm. from south edge of block and 11.8 cm. from east edge. True bearings: large brick chimney in Para, 1° 36′.2; outer gable end of shelter house on pier at Pinheiro, 42° 20′.9; tip of spire of São Sebastião Church, 262° 50′.2. Station *B* is 15.6 meters from station *A* in the line from station *A* to the large brick chimney in Para. Station *C* is 15.85 meters from station *B* in line from station *B* to large brick chimney in Para.

Rio de Janeiro, Federal District, 1910.—Three stations, *A*, *B*, and *C*, were occupied at Freitas Beach. They are on the beach about 250 meters west of present terminus of the Ipanema car line from Rio de Janeiro, on grass-covered sand above the high-water mark. Station *B*, the main station, is about 12 meters from edge of grass and about 20 meters from ridge of a small sand hill to the landward. It is marked by a wood post 3 by 4 by 36 inches (8 by 10 by 91 cm.). True bearings: center of top of pavilion on the summit of Corcovado, 166°46′.2; landward wireless telegraph pole at the bottom, 279° 52′.8; lighthouse on Rasa Island, 326° 09′.8. Station *A* is 23.6 meters 99° 52′.8 west of

SOUTH AMERICA.

BRAZIL—*concluded*.

Rio de Janeiro, Federal District, 1910—continued. true south from station *B*, being in line of station *B* and landward wireless telegraph pole. Station *C* is 18.3 meters from station *B* in line from station *B* to landward wireless telegraph pole.

CHILE.

Coronel, Concepcion, 1912.—Two stations, designated *A* and *B*, were occupied in vicinity of United States Coast and Geodetic Survey station of 1907. *A*, approximately same as 1907, is on sandy plain about three-fourths mile (1.2 kilometers) southeast of town, in line between slaughter-house and chimney of soap factory, about 100 meters west of sandy road leading to slaughter-house, on small flat knoll about 1.5 meters high and entirely bare of vegetation, and nearly in projected line of second street east of soap factory; marked by peg sunk below ground with empty glass bottles at side. True bearings: chimney at Lota Lighthouse, 25° 58'.7; Puchoco Lighthouse, 104° 29'.2; chimney at soap factory, 150° 01'.2; north gable of slaughter-house, 334° 58'.2. *B* is about 22 meters south 19° west from *A*; marked by peg. True bearings: chimney at Lota Lighthouse, 26° 00'.0; Puchoco Lighthouse, 114° 51'.9; chimney at soap factory, 151° 35'.8; north gable of slaughter-house, 332° 00'.4.

ISLANDS, ATLANTIC OCEAN.

BERMUDAS.

Agar's Island, 1910.—The principal Carnegie Institution of Washington station, *A*, is near the southwestern extremity of the island, about 150 feet (46 meters) from western extremity of spur extending westerly toward Two Rock Passage, about 35 feet (11 meters) from the south shore line and about 60 feet (18 meters) from north shore line. The spur is separated from main part of island by a shallow cove. Station marked by a native coral stone post 18 inches (45 cm.) long, projecting about 6 inches (15 cm.) above general surface; the projecting portion is squared to 10 by 10 inches (25 by 25 cm.) and covered with a very thin layer of cement, in which the diagonals are marked, the intersection of the diagonals defining the precise point. The following true bearings were determined: Gibbs Hill Lighthouse, 27° 51'.6; clock (left) tower at the dockyard, 146° 40'.9; flagpole at Port's Island (naval quarantine), 43° 32'.3. An auxiliary station, *B*, was established in 1910, 106.3 feet (32.4 meters) almost due west of the principal station near extremity of projecting point of rock.

Hunt's Island or Spectacle Island, 1910.—Station is near center of western part of island, in a low circular opening among trees where the soil is unusually deep; there are trees about 25 feet (8 meters) to the east and a clump of bushes 12 feet (4 meters) to the west. Two large cedar trees stand, one 18 feet (5.5 meters) to the south, and the other 22 feet (6.7 meters) southwesterly. The bare rock is about 12 yards (11 meters) to the north through bushes, and about twice as far to the south. The shore on the south is very flat, so that distance to water varies greatly with the tide. Marked by a cedar post set about 20 inches (50 cm.) in the soil and projecting slightly above surface with top marked by the letters C.I., made by driving in brass nails. The following true bearings were determined: clock tower at dockyard, 180° 34'.5; left edge of tank at north end of Boaz Bridge, 159° 18'.3; vane on the lighthouse, 351° 25'.5. An auxiliary station, *B*, 34.55 feet (10.53 meters) south of principal station, in exact line with clock tower at dockyard, was also occupied in 1910.

ISLANDS, ATLANTIC OCEAN.

FALKLAND ISLANDS.

Port Stanley, East Falkland Island, 1913.—Three stations, designated *A*, *B*, and *C*, were occupied. *A*, the "variation station" of British Admiralty, is on top of ridge at Navy Point in saddle between two clusters of outcropping rocks; marked by square stone projecting about 1 foot (30 cm.) above ground and having piece of marble with hole at center and word "variation" cut in, set in top. True bearings: flagstaff above town, 41° 56'.2; *B*, about 1.5 miles (2 kilometers), 63° 09'.3; wireless mast, 302° 27'.0. *B* is on hillside across bay from *A*, southwest of governor's residence, and south of quarters of naval surgeon, in slight depression north of clump of gorse bushes, 21.2 meters south of wire fence inclosing premises of naval surgeon. True bearings: *A*, 243° 10'.5; cathedral spire, 270° 48'.5. *C* is 50.5 meters true south 182° 51'.4 west of *B*, 45.0 meters north of east-west fence.

ICELAND.

Akranes, 1914.—On Akranes peninsula 9.7 nautical miles (16 kilometers) northward across bay from Reykjavik, in an open grass plot about midway between church and shore to south, 16.6 meters north of stone fence, 17.6 meters west of nearest corner of small house, and 13.4 meters south of a wire fence; marked by tack in top of wooden peg driven flush with ground. True bearings: church steeple below ball, 159° 56'.2; center chimney last house across bay, 294° 16'.9.

Grotta, 1914.—In small level pasture belonging to town pilot, on point of land northwest of Reykjavik, about 3 miles (4.8 kilometers) west-southwest from Reykjavik station *A*, about three-eighths mile (0.6 kilometer) east-southeast of Grotta Lighthouse, 100 paces northwest of slaughter-house and dwelling, 75 paces east of galvanized-iron shed, and 22.4 meters east of cement post about 21 cm. square and 1.05 meters high, standing on large irregular base and having in its top a round-headed copper bolt and on its south face a crown and letters "G. S." engraved; marked by tack in top of oak peg. True bearings: Grotta Lighthouse, 111° 38'.6; Reykjavik station *A*, 253° 17'.6; church spire, 298° 41'.2; observatory tower, 298° 44'.6.

Kialarnes, 1914.—On Kialarnes peninsula across bay from Reykjavik, very nearly in line from Hofwik Bay to Engey Island, 30 paces west of bank of Hofwik Fiord, 50 paces to bank in line with a group of very rugged rocks a short distance out, southward, and 30 paces southeast of a sod farm house; marked by brass tack in wooden peg driven flush with ground. True bearings: house across bay eastward toward Essia Mountain, 240° 07'.3; observatory tower, Reykjavik, 16° 18'.2.

Reykjavik, 1914.—Two stations, designated *A* and *E*, were occupied on an open grass plot on Engey Island, about 2 miles (3.2 kilometers) across harbor northward from Reykjavik. *A* is about 100 yards (91 meters) northwest of dwellings of two farmers who own the island, about same distance from north end of island, 90.08 meters northwest of small red light beacon standing near farm dwellings, and 32.51 meters northeast of a point in line between small red light beacon near farm dwellings and similar beacon at north end of island; marked by small cross in top of wooden stake driven flush with ground. True bearings: observatory tower flagstaff, 6° 27'.1; Catholic Church spire, 26° 55'.8; Valhusbakki beacon, 57° 20'.1; Grotta Lighthouse, 78° 27'.7; red light near north end of island, 117° 40'.8; church spire at Akranes, 153° 05'.4; nearest corner red and white house, 289° 51'.9; cleft in mountain, 308° 17'.1; red beacon near dwellings, 316° 50'.3; *E* is 33.30 meters west-southwest from *A* on azimuth line to Grotta Lighthouse; marked by small cross in top of

ISLANDS, ATLANTIC OCEAN.

ICELAND—concluded.

Reykjavik, 1914—continued.
wooden stake driven flush with ground. True bearings: observatory tower flagstaff, 6° 05′.6; Catholic Church spire, 25° 14′.4; Valhusbakki beacon, 57° 13′.1; Grotta Lighthouse, 78° 27′.7; red light near north end of island, 120° 49′.5; church spire at Akranes, 153° 10′.3; nearest corner of red and white house, 289° 40′.1; red light near dwellings, 305° 50′.9. Three auxiliary stations, designated *B*, *C*, and *D*, were also occupied. *B* is 52.45 meters east-southeast from *A*, and in range between *A* and corner of red and white house; *C* is 72.3 meters from *A*, in azimuth 128° 17′.1; *D* is 104.8 meters southwest from *A*, and in range between *A* and Valhusbakki beacon.

Videy Island, 1914.—On a small grassy knoll, at most westerly point of island, 12 paces and 10 paces from precipitous edge of island to north and east respectively. True bearing: station *A* on Engey Island, 85° 44′.9.

MADEIRAS.

Funchal, 1909.—The main station, designated *A*, is near center of parade grounds of College Barracks and as close as could be determined to station of Capt. F. A. Chaves, 1903 and 1906. The Cathedral spire is in true bearing 315° 16′.4. The secondary station, designated *C*, is on point west of Funchal, about one-eighth mile (0.2 kilometer) east of new fish cannery, on a level bluff about 60 feet (18 meters) above water and about 15 feet (4.5 meters) back from beach. Sail Rock is in true bearing 277° 16′.3. Auxiliary stations were established at both of these points and showed considerable local disturbance; *B* was 40 feet (12 meters) from *A*, and *D* was 42.5 feet (13 meters) from *C*.

ST. HELENA.

Longwood, 1913.—Four stations, designated *A*, *B*, *C*, and *D*, were occupied. Main station, *A*, is on triangular lawn west of house in which Napoleon died, 53.05 meters west-southwest from southwest corner of north post of yard gate, 34.1 meters northwest of west corner of masonry support for three water tanks, and 13.1 meters due north of point in line with flax hedge; marked by cross cut in top of spruce post driven flush with ground and covered with sod. True bearings: northeast corner of house, 82° 13′.7; flagpole at High Knoll Fort, 102° 31′.5; prominent rock on Signal Hill, 186° 32′.7; north gable of stone house on hill, 345° 54′.1. *B* is 26.4 meters west-southwest from *A* on azimuth line to northeast corner of house, 12.7 meters north of flax hedge, and 21.7 meters southeast of iron telephone pole; marked by cross cut in top of tent peg driven flush with ground. True bearings: northeast corner of house, 82° 13′.7; flagpole at High Knoll Fort, 102° 40′.1; prominent rock on Signal Hill, 186° 59′.0; north gable of stone house on hill, 345° 05′.2. *C* is 27.25 meters west-southwest from *B* on azimuth line to northeast corner of house, 27.9 meters south-southwest from iron telephone pole, and 11.6 meters north of flax hedge. True bearings: northeast corner of house, 82° 13′.7; flagpole at High Knoll Fort, 102° 49′.4; prominent rock on Signal Hill, 187° 26′.3; north gable of stone house on hill, 344° 14′.3. *D* is about 75 yards north of old magnetic observatory in open field, 11 paces north of fence along north side of yard in front of Mr. Fred M. Deason's house. True bearing: west edge of stone house, one-half mile (0.8 kilometer), 167° 33′.3.

WEST INDIES.

Culebra Island, Scorpion Point, Porto Rico, 1910.—Practically identical with that of the U. S. Coast and Geodetic Survey of 1903 and 1904, on line between

ISLANDS, ATLANTIC OCEAN.

WEST INDIES—concluded.

Culebra Island, Scorpion Point, Porto Rico, 1910—con.
the hydrographic signal "Scorp 2" and the triangulation station "Soldado," 7.9 meters from "Scorp 2," 3.6 meters from edge of bluff that stands at this place, the latter distance being measured in the direction of the "Soldado" triangulation station. The azimuth of the "Soldado" triangulation station as supplied by the U. S. Coast and Geodetic Survey is 314° 46′.5.

Vieques, Porto Rico, 1910.—Observations were made in the new absolute house of the observatory on the regular magnetometer pier and the regular earth-inductor pier, these two piers being designated as *New Absolute Observatory*. Stations *1* and *2* are in line with the azimuth pier of the observatory and the right-hand edge of Caballo Blanco Reef, which is 3.5 kilometers distant. Station *1* is 24.2 meters to the seaward of the azimuth pier. Station *2* is 26.4 meters to the landward of the azimuth pier. The tower of the lighthouse at Point Mulas is in true bearing from magnetometer pier 199° 20′.0; from station *1*, 200° 23′.1; and from station *2*, 198° 12′.5.

ISLANDS, INDIAN OCEAN.

CEYLON.

Colombo, 1911.—Three stations, designated *A*, *B*, and *C*, were occupied in western part of grounds of Colombo Observatory. *A* is 108 feet (32.9 meters) from southwest fence, 164 feet (50.0 meters) southwest of southwest corner of office building, 80.62 feet (24.57 meters) west of thermometer shelter, and 69.8 feet (21.28 meters) northeast of large tree; marked by cement block 3 feet (0.9 meter) long and 5 inches (12.7 cm.) square at top, lettered on top "C.I.W. 1911." True bearings: northwest corner of lunatic asylum, 55° 40′.6; small white upright over east gable of "Grasmere," the Surveyor-General's bungalow, 177° 25′.8, southeast corner of office, 235° 30′.3. *B* is 217.67 feet (66.35 meters) north of *A*, on azimuth line to "Grasmere." *C* is 84.62 feet (25.79 meters) north of *A*, on azimuth line to "Grasmere."

Colombo, Cinnamon Gardens, 1911.—In vacant lot owned by Mr. S. M. Fernando, on north side of Bogatelle Road, Cinnamon Gardens, opposite La Corniche Bungalow, 102.4 feet (31.21 meters) north of wire fence along road, 124 feet (37.8 meters) east of stone wall on west side of lot, and 19.2 feet (5.85 meters) northwest and northeast respectively from two palm trees.

JAVA.

Weltevreden (Batavia), 1911.—Two stations, designated *A* and *B*, were occupied in grounds of Royal Magnetic and Meteorological Observatory. *A* is 13.35 meters southwest of southwest corner of foundation of absolute house, 22.6 meters northwest of east end of brick wall at rear of grounds. True bearing: azimuth mark of observatory, line on concrete pillar near west side of main entrance, 178° 14′.1. *B* is on azimuth line from *A* to mark, 14.87 meters north of *A*, and 11.30 meters west of southwest corner of foundation of absolute house. For intercomparisons with observatory standards, observations were made on piers in absolute house of observatory, declination being observed on declination pier, horizontal intensity on piers *A* and *C*, and inclination with earth inductor on earth-inductor pier.

MAURITIUS.

Pamplemousses, 1911.—Four stations, designated *A*, *B*, *C*, and *D*, were occupied in grounds of Royal Alfred Observatory. *A* is central pier of absolute house.

ISLANDS, INDIAN OCEAN.

MAURITIUS—*concluded.*

Pamplemousses, 1911—continued.
True bearing: observatory azimuth mark, 0° 01'.3. *B* is 6.41 meters south of *A*, in line to azimuth mark. *C* is 42.38 meters south of *B*, in line from *A* to azimuth mark. *D* is dip pier of observatory, 1.53 meters west of *A*.

ISLANDS, PACIFIC OCEAN.

FIJI ISLANDS.

Suva Vou, Viti Levu Island, 1912.—Two stations, designated *A* and *B*, were occupied. *A* is reoccupation of C.I.W. station of 1906, and H.M.S. *Waterwitch* station of 1896; on north side of bay, about 2 miles (3 kilometers) from Suva, on point of land near missionary station of Seventh-Day Adventists; marked by concrete post projecting 18 inches (45.7 cm.) out of ground, and having an arrow and year 1896 cut on east face. True bearings: outer lighthouse, 31° 00'.0; lower lighthouse, 129° 54'.5; flagstaff on governor's house, 342° 36'.1; boathouse, 348° 35'.9. *B* is on same bluff, 2 meters from east edge of cliff, 32.4 meters north-northeast of *A*. True bearings: outer lighthouse, 31° 11'.0; flagstaff on governor's house, 343° 00'.4; boathouse, 349° 01'.3.

PHILIPPINE ISLANDS.

Antipolo, 1912.—Three stations, designated *A*, *B*, and *C*, were occupied at Antipolo Observatory. *A* is pier in absolute house. True bearing: mark on large mango tree, 359° 58'.8. *B* is on broad walk in front of variation observatory, 25.8 meters from middle of lower front step of observatory. True bearings: absolute observatory mark, 5° 47'.8; windmill top, 135° 18'.2; southeast corner of variation observatory, 188° 08'.2; staff of vane on wind-tower, 277° 07'.2. *C* is on broad walk in front of variation building, in line with *B* and mark on small bungalow at rear of hotel, 26.7 meters south of *B*, 59.9 meters from point 4 feet above ground

ISLANDS, PACIFIC OCEAN.

PHILIPPINE ISLANDS—*concluded.*

Antipolo, 1912—continued.
on mango tree on which is placed declination mark for absolute house. True bearings: center of windmill top, 143° 07'.9; southeast corner of variation observatory, 183° 16'.8; staff of vane on wind-tower, 263° 06'.7.

SOCIETY ISLANDS.

Papeete, Tahiti Island, 1912.—In eastern corner of tract of government land immediately south of Botanical Garden, about 106 meters south-southeast of gardener's house, 47.3 meters northeast of northeast cornerstone of windmill pump, 8.8 meters southeast and 12.7 meters southwest respectively from two cocoanut trees, 15.2 meters north of tropical chestnut tree, and approximately 15 and 41 meters respectively from west and north fences of tract. True bearings: windmill vane, 29° 46'.1; corner of house of chief justice, 107° 14'.2; east edge of gardener's house, 158° 02'.8.

Small Coral Island (*Papeete Harbor*), *Tahiti Island*, 1912.—Two stations, designated *A* and *B*, were occupied on small coral island about one-half kilometer west of white obelisk on Soactoi reef south of entrance to Papeete Harbor and not far from station of *Galilee* party in 1907, which, owing to changes in topography on account of storms and the building of small hospital and wharf, could not be recovered. *A* is on north extremity of island. True bearings: northwest corner of hospital, 4° 00'.9; channel gun, 240° 04'.0; cathedral spire, 267° 40'.4; north obelisk, 276° 13'.1 upper range-light, 295° 57'.7; south obelisk, 316° 51'.6; northeast corner of hospital, 49.6 meters, 345° 46'.9. *B* is on south extremity of island, about 88 meters south of *A*. True bearings: mountain peak on northeast end of Moorea Island, 100° 14'.2; northwest corner of hospital, 36.3 meters, 189° 56'.8; southwest corner of hospital, 227° 52'.0; upper range-light 292° 03'.2; south obelisk, 310° 26'.9.

EXTRACTS FROM DIRECTOR'S INSTRUCTIONS FOR CRUISES AND OBSERVATIONAL WORK ON THE CARNEGIE.

The following extracts from the Director's instructions to those in command of the *Carnegie*, from time to time, will serve to explain the routes prescribed for the vessel and the methods of observation adopted for the various kinds of work. They will aid in showing how the observations were made at successive stages of the work, and how the methods and instrumental appliances were developed and modified as experience suggested. It will be noticed that, although the *Carnegie* is a strictly non-magnetic vessel, nevertheless the instructions called for occasional swings of the vessel in order to make desired tests, both as to the absence of ship deviations and of "instrumental deviations" (see p. 18). From the discussion on page 436 it will be seen that the observations made on these swings served a useful purpose, and gave the means of judging as to the accuracy of determination of magnetic elements aboard the *Carnegie* under harbor conditions.

CRUISE I OF THE CARNEGIE, 1909–1910.

FROM ROUTE INSTRUCTIONS OF JULY 14, 1909, TO W. J. PETERS AT BROOKLYN.

1. Leaving *Brooklyn* as soon as feasible, and after the trial observations and swings at Gardiners Bay have been completed, a course will be shaped for St. John's, Newfoundland, crossing the 60th meridian in about latitude 41° to 42°.

2. *St. John's, N. F.*—The C. I. W. (Carnegie Institution of Washington) magnetic station of 1905 is to be reoccupied and such additional shore observations are to be made as may be found necessary. * * *

3. After the completion of the work at St. John's, the vessel will follow a course to Falmouth, England, as nearly direct as possible, crossing the thirtieth meridian in about latitude 51°. Such shore observations as may be required will be made, and the vessel will be swung in Falmouth Harbor.

4. *Leaving Falmouth* early in November, the sailing route will be followed to Madeira, and, after making there the requisite shore observations, proceed next to New York via Bermuda, intersecting the fortieth meridian in about latitude 22° north. * * *

5. *Bermudas.*—These islands are greatly disturbed magnetically and every care must be taken in the proper selection of stations for shore work.

6. *New York.*—Return should be made not later than about February 1, 1910. After the completion of whatever work may be necessary, the vessel will be turned over to the Tebo Yacht Basin Company for the copper sheathing of the bottom. * * *

FROM INSTRUCTIONS FOR SCIENTIFIC WORK ON CRUISE I.

1. Observe the three magnetic elements daily unless conditions prevent.

2. *Declination.*—Corresponding observations with the two compasses (C1 and D3) are to be made, whenever possible, and the causes of differences investigated.

3. *Observations with sea dip-circle.*—Loaded dip will be required only every third day, and in between the total-intensity work will be confined to deflection observations. In deflection work, for short distance, read extremes of arc; for long distance, set microscope-thread on middle of arc by method of repeated bisection. When combining dips, give results from regular dip needles 9 and 10 each double weight, and deflected dips, each distance, single weight, or what amounts to the same thing, treat the mean result from short and long distances as equivalent to a result with needle 9 or 10. The possibility of level error in dip observations requires attention. In addition to setting the foot-screws according to the foot-screw readings, the matter of whole turns should be controlled also for every mounting of the instrument. To facilitate this, brass gages should be made, or some other device be used. It is essential that the level position of the dip circle be controlled each time, and an entry be made on the dip sheets that this was done before the observations were made.

4. *Observations with sea deflector.*—Continue previous method, viz, read each position twice in succession and take simultaneous readings of course by Kelvin compass. Every care must be taken of the magnets; they must not be handled any more than necessary. For magnet 45, read vernier *A*, and for magnet 2L, vernier *B*.

5. *Shore observations with sea deflector.*—Always begin and end observations by reading on mark. Next read compass card before mounting deflecting magnet, and again, afterwards, for each magnet. (These observations will furnish declinations, both from the undeflected and deflected positions of the card.)

6. An abstract of the ship's log for a passage, together with the monthly journal, will be transmitted promptly to the Office.

7. To control effectively the ship work, the computations are to be kept up to date as heretofore and an abstract is to be made. Whenever discrepancies in the results, derived from the various instruments and methods, appear, every effort should be made by the observers to determine the cause, and to repeat the observations at the earliest moment.

8. *Atmospheric-electric observations.*—The observer, in addition to the magnetic work, will undertake whatever is feasible, and will conduct desired experiments, as directed, for supplementing the present information as to what is necessary to make this work successful.

9. *Meteorological observations.*—These observations are to be made in cooperation with the United States Weather Bureau and in the same manner followed on the cruises of the *Galilee*. They will be recorded on the forms supplied by the Bureau.

CRUISE II OF THE CARNEGIE, 1910–1913.

FROM ROUTE INSTRUCTIONS OF JUNE 4, 1910, TO W. J. PETERS AT BROOKLYN.

1. The *Carnegie* will sail from Brooklyn on her next cruise (No. II) not later than the 20th instant. You will please make all arrangements accordingly.

2. You will find inclosed two copies of the Schedule of the Cruise, accompanied by a blue print, showing the various courses and ports. Please note that the aim is to fill in the regions where magnetic data are especially needed. * * *

[The ports of call on this circumnavigation cruise, as finally settled upon, were: Brooklyn, Greenport (Gardiners Bay), Vieques (Porto Rico), Para, Rio de Janeiro, Montevideo, Buenos Aires, Cape Town, Colombo (Ceylon), Port Louis (Mauritius), Colombo, Batavia, Manila, Suva (Fiji), Papeete (Tahiti), Coronel (Chile), Port Stanley (Falkland Is.), Jamestown (St. Helena), Bahia, Jamestown, Falmouth, Greenport, and Brooklyn. The cruise was arranged with the view of encountering, on the various passages, the most favorable conditions possible, as to sea and weather, and having the best trigonometric conditions for the astronomical work. Consideration was also paid to the desirability of securing intersections with the previous tracks of the *Galilee*, the *Carnegie*, the *Gauss*, and the *Discovery*. The *Carnegie* sailed from Brooklyn June 20, 1910, and returned on December 19, 1913. For synopsis of cruise, see pages 165–170; also abstract of log, pages 333–347.]

INSTRUCTIONS OF JUNE 11, 1910, FOR SCIENTIFIC WORK ON CRUISE II.

A. *Magnetic Observations on Swings.*

1. En route to Vieques, Porto Rico, magnetic observations on swings are to be made in Gardiners Bay at same place as in 1909 (lat. 41° 06′ N.; long. 72° 13′ W.). It will suffice to secure for each element one complete swing with each helm, provided all necessary precautions are taken beforehand regarding absence of magnetic articles close enough to affect the results, and with respect to satisfactory condition of instruments. The swings for the various elements may be arranged by the Commander to suit the conditions; 8 equidistant headings will be taken.

2. *Declinations* will be obtained with both instruments (C1 and D3), especial care being taken with respect to level of D3.

3. *Inclinations.*—First helm: absolute dips with D. C. 189 (needle 10), observations on each heading being of same extent as for course, including reversal of polarity of needle; other helm: deflected dips will be obtained from the deflection observations under 4. (See precautions as to level of instrument under D3.)

4. *Total intensities.*—On second swing, called for in 3, make deflection observations with D. C. 189, needles 7 and 8, using both distances, and with face of needle 7, *D* and *R* on each heading.

5. *Horizontal intensities with sea deflector 3.*—First helm: use magnet 45, and on the other, 2L, at distances 1 and 3 on each heading, obtaining as many sets as possible. (Special care should be taken to see that the instrument is in best condition, and that deflecting magnets are properly placed in position. Sufficient time must be allowed on each heading for the compass card to settle down, and precautions taken to set up as little motion as possible in the liquid.)

6. The Commander is at liberty to repeat any of the prescribed observations found necessary.

7. For the present, other places of swings will not be designated. Should a port be found, however, in the Southern Hemisphere, where conditions are suitable, it would be desirable to swing vessel once more towards the end of the present year, or possibly at Cape Town. * * * [The vessel was actually swung in Gardiners Bay (Aug. 31–Sept. 2, 1909; Dec. 15, 16, 1913), at Rio de Janeiro (Dec. 23, 24, 1910), at Falmouth (Oct. 4, 1913), and 8 times at sea.]

B. *Magnetic Observations on Course.*

1. The attempt will be made to secure some magnetic data daily—the three elements, whenever conditions permit. The method of observing each element in duplicate, simultaneously with different instruments and observers, is again to be followed as rigidly as possible. Observers are again to alternate in observing any particular element. It is desirable, whenever conditions permit, to obtain the three elements, as nearly as possible, for the same geographic position, but it is realised that this is not so readily accomplished as far as the declinations are concerned, since for this element the time of observing can not be arbitrarily chosen. The dips and intensities should be observed, as far as practicable, between 2 and 5 p.m., local mean time—in general, between 3 and 4 o'clock; the diurnal-variation corrections at these times will usually be negligible.

2. *Declinations with C1 and D3.*—Observations with the latter instrument, if made with care, will afford a check upon the former.

3. *Inclinations.*—The observations will consist of absolute dips with needles 9 and 10, D. C. 189 and deflected dips, needles 7 and 8, using two distances whenever possible. In the computation, double weight will be given, in general, to each direct dip, and single weight to each deflected dip or double weight to the mean of two deflected dips. Level of instrument on the gimbal stand has been found to be a very important matter; the whole error of level may enter into the dip, and it is not eliminated by the method of observation, nor by taking the mean of several needles. Every opportunity will be taken to control this source of error, and the necessary precautions will be observed regarding heights of foot-screws, etc., as prescribed on the previous cruise. [Beginning at Tahiti in 1912, a reversible gimbal-stand was used; see pages 196–197, and Pl. 14, Fig. 5.]

4. *Total intensities.*—Always make deflection observations with D. C. 189, needles 7 and 8, using two distances whenever possible. When short distance becomes unavailable, then observe loaded dips, needle 8 (weight 11) two sets, next deflections long distance, face of needle 7, *D* and *R*, and close with two sets loaded dips.

5. *Horizontal intensities.*—These observations will be made with the sea deflector supplied, using both magnets and both distances, observing precautions noted under A 5; as many sets will be obtained as possible during the dip and intensity observations in forward observatory. Distances 1 and 3 will be used until otherwise instructed. Recorder will take simultaneous readings of ship's head with Kelvin compass.

6. *General remarks.*—Observers should use every reasonable endeavor to guard against instrumental changes and should try to ascertain causes of errors immediately upon discovery. They must be careful regarding presence of articles on their persons, or on others close by, likely to affect the observations. Whenever the instructions do not exactly fit the conditions to be met, the Commander, in accordance with his previous experience, will make the necessary modifications and amplifications. The Commander will also see to it that every care is taken as to holding of course during observations. In order to secure effective control of the work, he, at least once a week, will make a complete set of observations with each instrument; these need not be additional observations, but a part of the regular scheme of observation; in connection with these observations a general report will be made of the condition of instrument. To guard against systematic errors as far as possible, he will exercise a similar control on all computations.

D. C. 189 appears to be an exceptionally good instrument and should therefore have every care bestowed upon it to guard against accident. No. 203 is only to be used in case of emergency, but observations will be made with it regularly on land.

C. *Shore Magnetic Observations.*

1. Until otherwise advised, the same directions apply in general as heretofore, subject to such modifications as the Commander finds necessary according to circumstances. It will be desirable in the determination of the constants for the ship instruments to make the observations either simultaneously with the land instruments, or at such time of day when the diurnal-variation corrections are small, or variable in sign. Descriptions of certain stations to be occupied are furnished, but the Commander is at liberty to add additional ones as he may find necessary and possible.

D. *Computations of Magnetic Observations.*

1. Until otherwise instructed, the computations on the present cruise will be made with the same constants throughout as already supplied. In other words, the constants are not to be changed with every new determination; so also in the land observations for determination of new constants, the computations will be made with the old constants and the corrections, instead, determined. These corrections will be distributed along the cruise and will be applied on the abstract of results. There will thus be avoided frequent changes in the computations on the observation sheets. These computations when revised will remain unchanged thereafter unless some error is discovered in computation. This new method applies to all the magnetic elements. The logarithmic work will in general be carried to four places.

E. *Atmospheric-Electric Observations.*

1. Such observations are to be made as time of observer will permit. They will, in general, be of the same character as on the previous cruise, with such modifications and additions as the observer in consultation with the Commander finds desirable.

F. *Atmospheric-Refraction Observations.*

1. These observations will be continued and amplified as may be found possible; the precise directions are left to the Commander.

G. *Meteorological Observations.*

1. These observations will be the same as on previous cruise, with such extensions as the Commander finds possible.

H. *Astronomical Observations.*

1. Astronomical observations will be made as on previous cruise in duplicate or triplicate, as the Commander directs, and as often as may be necessary for effective control of geographic positions.

I. *Other Observations.*

1. The Commander will be allowed to include such additional scientific work as he finds possible on board the *Carnegie*. His attention is called to the need of additional observations on ocean currents.

Instructions of August 26, 1910, for Swing Magnetic Observations Subsequent to those at Gardiners Bay.

1. It will in general suffice to secure for each element one complete swing with each helm, provided all necessary precautions are taken beforehand regarding absence of magnetic articles sufficiently close to affect the results, with respect to satisfactory condition of instrument, etc. The swings for the various elements may be arranged by the Commander to suit the conditions; 8 equidistant points will be taken. The Commander is also at liberty to repeat any of the observations or swings as he may find necessary, without unduly prolonging stay in port. Places of swing will not be designated, but will be left to the judgment of the Commander with the remark that it

will suffice for the portion of the cruise to Cape Town to make swings at the most southerly port and at one intermediate between Gardiners Bay and the southerly port selected. In the absence of further instructions, the same considerations apply to future portions.

2. *Declinations* will be obtained on each heading, both with C1 and D3, especial care being taken with respect to level of latter. A swing with both helms is required separate from that for the other elements.

3. *Inclinations.*—One helm, absolute dips D. C. 189, needle 10 (or No. 9 in case it should prove more satisfactory), readings on each heading being of same extent as for course observations, inclusive of reversal of polarity of needle; other helm, deflected dips will be obtained in connection with deflections under 4. The same precautions regarding level of instrument apply as in course observations.

4. *Total intensities.*—One helm, making only deflection observations, D. C. 189, needles 7 and 8, using long distance only but having face of needle 7, D and R, each heading. (If swing is repeated, and short distance is available, then use it for deflected dip and total intensity, and on swing with other helm, use the regular dip needle, *e.g.*, No. 9, not employed on first swing.)

5. *Horizontal intensities.*—Both helms, sea deflector 3, using on one swing magnet 45, distance 3, and on the other, 2L, distance 1, on each heading. At least two minutes will be allowed for the deflected card to come to rest, and invariably the usual four positions will be taken on each heading, making from 3 to 5 readings of card on each position, according to circumstances. The aim should be not to extend the set beyond 12 minutes, if possible. Precautions must be taken to assure satisfactory condition of instrument and maintenance of deflection distances. (If swing be repeated, use magnet 45, distance 1, one helm, and magnet 2L, distance 3, other helm.)

DIRECTIONS OF AUGUST 30, 1910, FOR SHORE MAGNETIC WORK.[1]

A. Use the earth inductor at all primary shore stations ("primary" in the sense of stations where instrumental constants are determined), rather than at only a part of them. As there are available for observational work but 3 observers, it is desirable to establish for the purpose of constant-determinations not more than 3 stations at the primary ports: A, B, and C. The 3 stations should be chosen so that 2 of them will be on lines of known azimuth from one of them (in cases where good marks are not available, use might be made of temporary ones, set, however, at least 500 feet distant from closest station and suitably marked to prevent displacement or loss during the period of work). Designating the successive days of observation as 1, 2, 3, 4, and so on, dropping out Sundays and holidays, the following program will suffice:

1. Location of station site. Local-disturbance tests by means of dip-circle compass 201, taking magnetic bearings of the same line at various points over site. Selection of station A, and marks. Azimuth and latitude work at A; measurements of horizontal angles. Selection of stations B and C. Descriptions of stations. Setting up of tents.
2. Magnetometer 4 at A, 2 at C (3 complete sets with each magnetometer, a set consisting of D, H, H, D, with deflections at 2 distances); sea deflector at B.
3. Magnetometer 2 at A, 4 at C (3 complete sets with each magnetometer); sea deflector at B.
4. Magnetometer 2 at A, 4 at B (3 complete sets with each magnetometer); marine collimating-compass at C.
5. Earth inductor at A; dip circle 201 at B (4 determinations of I with each of needles 1 and 2, or with any other pair selected and simultaneous observations with earth inductor).
6. Earth inductor at B; dip circle 201 at A (4 determinations of I as on day 5).
7. Earth inductor at B; dip circle 189 at A.
8. Same as 7. On days 7 and 8, 4 observations for I are to be made with each needle of the pair regularly used, and 3 to 4 determinations of the total-intensity constants of the regularly used intensity pair; simultaneous observations with earth inductor.
9. Earth inductor at B; dip circle 203 at A (2 sets for I to be made with each needle-pair for use in emergency with this instrument, and 2 determinations of intensity constants for the pair to be used in emergency; simultaneous observations to be obtained throughout with the earth inductor).

[1]See also later directions, pages 321 and 322.

B. The above program, at primary stations, calls for the services of 3 observers on days 1, 2, 3, and 4. On days 5 and 6, the third observer might complete azimuth or latitude work, and compute the work of the first four days. At the ports where swing observations are to be made, days 7, 8, and 9 might be devoted by the third observer, using magnetometer 4 and dip circle 201, to observations at stations suitably selected for determining the distribution of magnetism in the region of the proposed swing. The order of program may be varied to suit the conditions encountered. The work with 203 (the reserve sea dip-circle) may be omitted at every other station.

C. To determine the distribution coefficients for the land magnetometers, it will suffice to make deflections at 3 different pairs of distances at the 3 stations. In no case, however, with magnetometers of the Department type Nos. 2–10, should deflection distances less than 25 centimeters be used. Suitable pairs of distances would be 25 and 30, 27.5 and 35, and 30 and 40 cm.; in cases where the deflection angles at distance 40 are so small as to be difficult of determination with the requisite accuracy, deflections at the first two pairs of distances will be sufficient if suitably distributed through the work.

DIRECTIONS OF SEPTEMBER 7, 1911, FOR OCEAN OBSERVATIONS WITH SEA DEFLECTOR 4.

1. Follow the general scheme at present in use and as given in "Memoranda regarding sea deflector 4, February 13, 1911," taking 5 readings, in each position, for both sea deflector and Kelvin compass. Two full minutes must be allowed, after magnet is in position, at beginning of observations for each magnet (not distance), as also between each reversal of sights (bowl); one full minute must be allowed between all other positions; allowing about one minute for the 5 readings, the minimum time required for a half-set, from beginning of reading to end, will be 8 to 10 minutes, allowing for interruptions and repetitions.

2. Every possible precaution is to be taken against setting up motion of liquid in bowl by avoiding sharp or rapid reversals of sights. Care must also be taken to avoid possibility of card being lifted off the pivot during reversals of sights by the action of deflecting magnet; the latter, during such reversals, is to be removed and held far enough away, and then replaced.

3. Time and temperature are to be recorded a few seconds before the beginning of a set, so as to correspond as nearly as possible with actual beginning of set. Endeavor should be made to secure as uniform conditions of temperature as possible during the time the deflecting magnet is above and when below the card. To secure these conditions, the observing dome should be covered sufficiently to prevent the Sun from shining directly on the magnet or on the card; also the binnacle door is to be kept open throughout the series of observations.

4. To vary conditions, and to give each magnet the same treatment, begin on alternate days with magnet 45, distance 1, and magnet 2L, distance 1.

5. It should be kept in mind that the careful work of the deflector-observer may be vitiated by the recorder's poor readings of ship's head with the control (Kelvin) compass. There should, therefore, never be any hesitation to repeat observations with deflector and compass, whenever necessary. Readings during rapid motions of compass cards should be avoided as far as possible. The deflector-observer, after making several approximate settings at beginning, should aim to make settings by moving sight-line slightly beyond the 0° or 180° of card, and then working back to desired position; the direction in which this is done should be alternated, once from the right, next time from the left, etc. The sighting slit is to be used preferably, as it affords least opportunity for parallax or "personal equation."

6. Every possible care must be bestowed on the preservation of constancy of magnetic moments of magnets.

7. Upon conclusion of deflector observations, the bowl will be clamped.

GENERAL DIRECTIONS OF SEPTEMBER 7, 1911, FOR SHORE OBSERVATIONS.

After paying attention to the general remarks contained in directions of August 30, 1910 (see p. 320), according to which the shore work has been done hitherto, the observations may now be confined to the following, two stations being selected as free from local disturbing influences as surroundings permit, and care being taken to have, as far as possible, the same height above ground of magnets of the various instruments:

1. Magnetometer 4 (or No. 2, if found preferable) at *A*, sea deflector 4 at *B*, simultaneous *D* and *H* observations (not less than 3 good sets of each element and with each instrument). For each set, the footscrews, or the bowl as the case may be, will be oriented differently. To overcome possible sticking of the deflector card, drum on glass cover before each reading in both *H* and *D* work. The deflector *D*-observations will be made before and after the deflections by observing magnetic bearing of mark and using lowest part of wire.

2. Magnetometer 4 at *B*, deflector 4 at *A*; same observations as for 1. Observers will exchange instruments but not stations. With proper care, the station difference, *A–B*, will be derived from observations 1 and 2, with sufficient accuracy for the immediate purpose.

3. Earth inductor 2 at *A* and D. C. 189, or its substitute, at *B*; simultaneous observations; dip needles the same as those used in the ocean work, supplemented by another needle for possible future use, as selected by the Commander. Besides regular dips, complete total-intensity observations, inclusive of loaded dip, are required. As many sets as possible (not less than 3 for direct dip and 3 for total intensity) are to be secured. The manner of scraping or tapping the brass knob in observing with sea dip-circle appears to require attention; theoretically, the conditions at sea should be simulated as closely as possible.

4. Earth inductor at *B* and D. C. 189 at *A*, observers exchanging instruments but not stations. Same observations as for 3. (The absolute value of *H* will be derived from the magnetometer observations of the previous two days.)

5. Determinations of declination-constants by Sun observations and bright-line method with deflector 4 during the most suitable time. As many sets as possible under varying conditions are to be secured, not less than two observers taking part. The constants for the marine collimating-compass will be determined as the Commander may direct.

6. Such observations as found necessary are to be repeated during the available time.

7. The above scheme requires two careful observers for successful execution. Where comparisons are to be made with local instruments, *e. g.*, at Batavia, then these are to be included in the above scheme as found best, a third observer, if necessary, taking part and following the special directions for comparison work. The most experienced observer available is required for the observatory comparisons; on these, special care must be bestowed.

INSTRUCTIONS OF AUGUST 13, 1913, FOR WORK AT FALMOUTH.

Shore Work.

1. *Trefusis Point*, as in 1909, to be the main station for general intercomparisons of instruments and determination of instrumental constants, provided that this station is still found satisfactory; otherwise some suitable place near by is to be selected. The directions regarding reoccupations of old stations will be explicitly followed.

2. *St. Anthony* (C. I. W. 1909) to be reoccupied, using one of the magnetometers and a good land dip-circle, and obtaining complete observations on 2 days.

3. *Porthallow* (British Magnetic Survey, 1890) to be reoccupied, as nearly as conditions permit, using a magnetometer and a good land dip-circle, and securing complete observations on 2 days.

4. *Truro* (British Magnetic Survey, 1890). Same remark as for No. 3.

5. *Falmouth Observatory.*—The complete reoccupation of the observatory station on one day would be desirable.

6. *General note.*—All stations are to be marked in some manner, besides taking the usual angles and making such measurements to nearby objects as may be possible.

Ocean Work.

1. Observations are to be made of the three magnetic elements during complete swings of the vessel, both helms, arranged in best manner possible, and at such a time as the Commander may find most suitable, the place of swing to be the same as in 1909 (latitude 50° 06′ N, longitude 5° 01′ W). * * *

(*b*) In view of the new conditions, caused by the recent structural work and alterations of vessel and by the installations of the atmospheric-electric instruments within close proximity to the mounts for the magnetic instruments, it will be highly desirable to swing vessel and make complete observations as often as conditions may permit, in order to make certain the absence of deviation-corrections. During these swings, the atmospheric-electric instruments are to be in place, and in operation, just as when the regular observations with these instruments are made. It may suffice, for the present year (1915), to make these swings at Gardiners Bay, Colon (or Panama), Honolulu, Dutch Harbor, and Port Lyttelton. In view of the possibility of local disturbance at some of these ports, especially Honolulu, and perhaps also Dutch Harbor, it will be desirable to make some swings also at sea. The aim should be to get as large a range in magnetic latitude as possible.

(*c*) The shore observations at Gardiners Bay may be omitted. The shore work at Colon (or Panama) may be restricted to the absolutely essential observations and comparisons. At Honolulu, where a longer stop is contemplated, the shore observations and comparisons of instruments will be made according to the complete scheme for such work. Here also comparisons will be obtained with the magnetic standards of the Honolulu Magnetic Observatory. The shore observations and comparisons at Dutch Harbor, in view of the high magnetic latitude, should be made as complete as conditions will permit. Similar observations on arrival of the vessel at Port Lyttelton will be made at the Christchurch Magnetic Observatory, and an intercomparison of standards will be secured. Information regarding the shore stations and the places where the *Galilee* was swung at Honolulu and Port Lyttelton is supplied on separate sheets.

II. *Atmospheric-Electric Work.*—(*a*) The detailed directions supplied for observations under this head will be followed.[1] With the addition of another observer to the vessel's scientific staff, it will now be possible to assign one observer practically entirely to the atmospheric-electric work. However, in order to secure simultaneity of determination of the various electric elements, it will be necessary to have also an auxiliary observer take part in this work. The principal observer, in return, will have to render any assistance required in the successful execution of the other work of the *Carnegie*. * * *

III. *Atmospheric-Refraction Work.*—The observations will be made in accordance with the detailed directions supplied.[1] It is hoped that special attention will be paid to these observations, in order to secure desired improvement. * * *

IV. *Barometer and Boiling-Point Work.*—See detailed directions.[1]

V. *Meteorological Observations.*—See detailed directions.[1]

IV. *Astronomical Observations* —See detailed directions [1]

VII. The assignment of each observer's specific duties is left to the Commander's discretion.

[1]The detailed directions are described in the special reports dealing with the various kinds of work. For those pertaining to the atmospheric-electric work, see pages 376–397.

with a force 4, Beaufort scale. The ship's approximate position was latitude 30°.8 south, and longitude 173° west. The nearest land was coral atolls, about 200 miles westward.

b. A very heavy clap of thunder occurred on June 4 at 1 p. m. in approximate latitude 19°.5 south and approximate longitude 169°.9 west, about 20 miles southeast of rocky and timbered islands. The wind of force 5 was from east-southeast.

c. At 10 p. m. of the same day thunder and lightning were again noted in latitude 19°.3 south and in longitude 170°.4 west, about 30 miles from the same islands. The wind was east, with force 4.

7. An examination of the record also reveals the following facts, which appear to have an important bearing on the question referred to in first paragraph:

a. There was no recorded occurrence of streak-lightning without the accompanying thunder.

b. Displays of flash and sheet-lightning, unaccompanied by thunder, were seen on one occasion as high as 70°, but usually the recorded angular altitude was not above 35°.

c. An important fact may be deduced from one of the recorded storms, viz, the varying time-interval between flash and clap, recorded in the lightning storm of October 10, clearly indicated the approach and recession of the storm, and showed that the thunder was lost to the *Carnegie's* observers when the storm was over 5 miles distant, as determined by the first and last intervals of about 20 seconds.

d. Several times lightning, unaccompanied by thunder, was seen in calm weather, and only once was it observed when the wind force exceeded 4 of the Beaufort scale. From these facts it may be concluded that the noise on ship is not the reason for the apparent silence of some lightning-storms at sea.

e. The record shows, however, that thunder was heard at no greater distance than 600 nautical miles from land, which in this extreme case was of such mountainous character as would tend to intensify the thunder.

It may be concluded from 7*a*, 7*b*, 7*c*, and 7*d* that many lightning storms are too distant to be heard, while from 7*e* it can only be said that, if the presence of land is necessary to make audible the sound of thunder at sea, as has been suggested, then it is possible that the land may be very distant at times, so far even as 600 miles.

The facts thus far noted are yet too few to warrant any final conclusions. It is expected that additional data will be available before the present cruise of the *Carnegie* will have ended.

J. P. AULT: ON THE SUB-ANTARCTIC VOYAGE OF THE CARNEGIE FROM LYTTELTON TO LYTTELTON, VIA SOUTH GEORGIA, DECEMBER 6, 1915, TO APRIL 1, 1916.

I beg to submit the following report on the circumnavigation trip of the *Carnegie* from Lyttelton to Lyttelton via South Georgia, December 6, 1915, to April 1, 1916.

For the first week after leaving Lyttelton the winds were mainly from the SSW, forcing us considerably to the eastward of our route; so much so that we sighted the Antipodes, bearing south, distant 20 miles, on December 9, and would have passed over the charted position of the Nimrod Group had the wind remained in the south another 12 hours. It had not been the intention to go near this group, but the adverse winds sending us so near them, it was decided to stand on toward the east another day, to endeavor to sight them; but the wind shifted to the north 12 hours too soon and we passed 40 miles to the SW of the position. [The Nimrod Islands were stated to have been seen, at a considerable distance, by Capt. Henry Eilbech in the *Nimrod* in 1828, who placed them in about 56°.5 S and 158°.5 W.[1]]

On December 7, a mirage presenting the appearance of distinct and extensive land was seen in the west, in the direction of Banks Peninsula, which was 190 miles distant at the time.

We crossed the 180th meridian December 9, so repeated the date as December 9 (2). Our first piece of ice was sighted on December 18, lat. 60° 12′ S, long. 150° 46′ W, and on December 19, 30 icebergs, some being over 400 feet high and 1 mile long, were passed. We had snow on December 18, 19, 20, and 21, and rather wintry weather. The barometer dropped to 28.26 inches on December 18, during the snow storm. No icebergs were seen after December 24 until January 10, just before arrival at South Georgia, when 8 or 10 good-sized bergs were passed.

As our route lay near the charted position of Dougherty Island, we determined to look for it. On the afternoon of December 24, the cry of "land ahead" was given and we saw what appeared to

[1]See footnote, page 327.

be a bold, dark rock island. Immediately our course was shaped to pass near it. Everyone was convinced that either a new island had been discovered or that the position given for Dougherty Island was very much in error. It seemed to be a rocky cliff with a snow cap. Nearer approach, however, proved that the supposed island was an iceberg, 225 feet high by ½ mile long. The light was reflected from the perpendicular ice-wall in such a way as to give the berg the appearance of a huge dark rock. The morning of December 25 found us within 3 miles of the position given for Dougherty Island. The weather was cloudy but the seeing was good. Nothing could be seen from the masthead. I went aloft myself every half hour while we were passing the position given for the island. Had anything over 100 feet high been within 35 miles of the vessel in any direction we would have seen it. At $3^h 40^m$ a. m., December 25, Dougherty Island should have been 3 miles SE of us. There was nothing visible within a radius of 35 miles at the time. The island has either been charted in the wrong place, or it has disappeared, or possibly it was an ice-island. Our experience on December 24 would confirm the possibilities of optical illusions. The *Carnegie's* track (see Fig. 14) extended from lat. 59° 28′ S, long. 123° 17′ W, to lat. 59° 08′ S, long. 110° 10′ W; daylight and good seeing were had all the time. If any one else attempts to locate the island, he should try either 40 miles south or 40 miles north of the charted position. We assumed the island to be at 59° 21′ S, and between 119° 10′ W, to 120° 20′ W. [Dougherty Island was supposed to have been seen by Capt. Dougherty in the *James Stewart* in 1841, who located it approximately in latitude 59° 20′ S and longitude 120° 20′ W. In 1859, Capt. E. Keates in the *Louise* sighted an island, assumed to be Dougherty, assigning the position to it: 59° 21′ S and 119° 07′ W.[1]]

December 30 and 31 were the first fine days experienced since our departure from Lyttelton. In spite of storms, rain, snow, fog, and prevailing cloudy weather, we succeeded in getting declination observations daily, and averaging twice daily during the entire trip. This was accomplished by taking advantage of every opportunity and spending considerable time standing by. Frequently we would make six or more trips to the bridge before being successful. At other times observations would be made during the only 5 or 10 minutes that the Sun was visible on the entire day.

The winds were mainly from the westerly semicircle, north and northeasterly winds with high and falling barometer, shifting to northwest and west when the barometer began to rise; rain and mist occurred nearly every day. Fogs were quite frequent, but not of long duration.

The entire party has enjoyed thus far the very best of health, and the weather has not been very severe. It has been more enjoyable in fact than a trip through the hot tropics.

We arrived at King Edward Cove, South Georgia, January 12, $9^h 30^m$ a. m., going the last 24 hours under our auxiliary power. The total run from Lyttelton to South Georgia was 5,440 miles, or an average of 144 miles for 37.9 days; the total distance logged was 6,010 miles.

The *Carnegie* left South Georgia at 7 p. m., January 14, 1916, towed out of harbor against a heavy head-wind by the steam whaler *Fortuna*. In the following days we realized that we were in climatic conditions quite different from what we had experienced previously. Icebergs appeared in increasing numbers, and fog was almost continuous. We will long remember January 18 as the only day during the entire trip of 4 months when we failed to obtain observations of the magnetic declination. The Sun was visible for only 3 seconds during the entire day, giving no opportunity for observations.

Larger icebergs were seen as we neared Lindsay Island, one looming up through the fog like a vast extent of dark land with the bright ice-blink reflected from the fog above it. We encountered an ice stream where small pieces were too numerous to dodge.

On January 22 we passed along the north coast of Lindsay Island about 3 miles offshore, obtaining a good view of this lonely, desolate place, with its deep mantle of snow and ice, surrounded with the wrecked icebergs that have come to grief on its shoals. A delegation of 6 penguins came out to greet us, the only ones seen in this vicinity.

The island agrees almost exactly in appearance and outline with the description and sketch given in the British Admiralty's Africa Pilot, Part II, 1910. It was surveyed by the German Deep Sea Expedition of 1898 in the *Valdivia*. They gave the position for its center as latitude 54° 26′ S, longitude 3° 24′ E. Our observations place its center in latitude 54° 29′ S, longitude 3° 27′ E, or

[1]According to *Nature*, vol. 97, No. 2431, June 1, 1916, page 237, "in 1909, on the homeward voyage of the *Nimrod*, with Sir E. H. Shackleton's Antarctic Expedition, Capt. J. K. Davis made a thorough search for the Nimrod and Dougherty Islands, and failed to find them; they were in consequence removed from the last edition of the Prince of Monaco's bathymetrical chart of the oceans."

about 3 miles from the position assigned by the *Valdivia*. This is a very close check in position for these regions, and we had no difficulty in locating the island. When our reckoning had placed it about 10 miles southeast of the vessel, we were able to locate it in the proper direction by noting the outline of a snow-covered glacier which appeared motionless through the shifting rifts in cloud and fog.

Some authorities have called this island "Bouvet Island," thereby causing a little confusion. H. R. Mill in his book "The Siege of the South Pole," 1905, gives a couple of pages to a description and picture of Lindsay Island, but names it "Bouvet," and gives as its position the latitude and longitude quoted above from the British Admiralty Pilot as that of Lindsay. Both books give as their authority the German Deep Sea Expedition of 1898. The British Admiralty Pilot states that "In November, 1898, the island (Bouvet) was searched for unsuccessfully by Captain Krech, of the German Deep Sea Expedition vessel *Valdivia*. Its position must, therefore, be considered uncertain." We agree with this conclusion, since we check so well the *Valdivia's* position of Lindsay Island.

Stieler's Hand-Atlas, 1907, publishes a map of Bouvet in a small insert with its south polar charts. The position given, the coast outline, and appearance are those of Lindsay Island.

Did Captains Bouvet and Norris see Lindsay Island or some island that has never been seen again? They reported it, Captain Bouvet in 1739, and Captain Norris in 1825, and placed it in latitude 54° 00′ S to 54° 15′ S and in longitude 4° 30′ E to 5° 00′ E, or about 15 miles north and about 50 miles east of Lindsay. We know that this position is seriously in error, for Cook, Ross, and Moore searched unsuccessfully for this island while on their various Antarctic cruises.

After taking bearings of Lindsay Island and such views as the weather and clouds permitted, we stood east in the hope of sighting Bouvet Island. Unfortunately, drifting ice, though in small pieces, became so thick that we thought it best to change our course to the north to avoid delay in this locality. So disappeared our chance of sighting either Bouvet or Thompson Islands.

Shortly after leaving the vicinity of Lindsay Island, it was decided to stand northward toward the Crozet Islands, so as to cut the isogonic lines at a greater angle.

When within 30 miles of the southwest point of Kerguelen Islands the weather became unfavorable for making the land, fog set in, and a gale began to blow, with a rapidly falling barometer. The vessel was immediately headed south to avoid outlying dangers, and when clear the course was set toward Heard Island. The season was advancing, and as a large area remained to be covered before our return to Port Lyttelton, a delay of a week or more in order to land at Kerguelen seemed unwarranted. This was February 6, and in the evening a copper box, tightly sealed, containing abstracts of all results to date, was set adrift on a float. The following was stamped on the copper box with steel dies: "Mail to the Carnegie Institution, Washington, D. C., U. S. A., from Yacht *Carnegie*, February 6, 1916." The float was set adrift at 8 p. m. in latitude 50° 14.′3 S, longitude 68° 19.′2 E. The only sign of human kind seen during 4 months, except at South Georgia, was a corpse floating in the open sea, about halfway between Heard and Kerguelen Islands, far from land. This was on February 7, at latitude 51° 12′ S, longitude 71° 26′ E.

On February 8 our course was set to the northward to intersect the *Carnegie's* track of 1911, and to determine the annual change of the magnetic elements. We made the first intersection in good time, but encountered head winds and later a calm, when attempting to make the second crossing. With the aid of the engine, however, we were able to make the desired point.

The annual changes determined were as follows: 17′ in declination, increasing numerically west values, as opposed to 8′ shown on the charts; —2′ in inclination, increasing numerically southerly dip; and —0.0007 C. G. S. in horizontal intensity, the value of this element decreasing.

The brief rest in quiet seas and in warm sunshine was very welcome, but the season was advancing and we were obliged to turn southward again and plunge into the dark and stormy regions of the "roaring forties and furious fifties." The stormiest period of the trip awaited us. The heaviest gales and roughest seas yet encountered were experienced, but the vessel stood the strain well.

As the *Carnegie* proceeded south toward the region of Queen Mary Land, the chart errors in declination constantly increased until, in the region of latitude 60° S, longitude 110° E, they reached a maximum of —12° for the United States and British charts, and of —16° for the German chart, *i. e.*, the charts gave values of west declination numerically too small by 12° to 16°.

On March 23, during magnetic observations in the afternoon, the horizontal intensity ranged from 0.098 to 0.110 C. G. S., possibly indicating a magnetic disturbance of some kind.

One iceberg was seen on March 1, the only one encountered since January 28. Owing to the decrease in horizontal intensity and the consequent uncertainty of the compasses, it was decided to turn to northward on this date, latitude 59° 24′ S having been reached. A few hours before turning northward a south wind sprang up, so it was well that we continued no farther in that direction.

The portion of our route extending into the Australian Bight was accomplished without special difficulty, and latitude 39° 29′ S was reached. Going south again, the *Carnegie* sailed as far as latitude 57° 25′ S, obtaining the low horizontal intensity of 0.086 c. g. s.

Owing to conditions of weather and lateness of season, it was thought best to head directly for Port Lyttelton, considering that we would intersect at good angles all isomagnetic lines.

FIG. 14.—Showing Track of the Carnegie's Sub-Antarctic Voyage, December 6, 1915, to April 1, 1916.

The Snares were sighted early on the morning of March 29. They were almost exactly where we expected to see them, so we knew that our chronometers were giving us nearly correct longitudes, after 4 months of hard usage and with the wide range in temperature obtained in the cabin on account of the presence of the heating stove.

Observations for intensity and inclination were taken every day regardless of conditions, even when the vessel was hove to in a hurricane and was being tossed about like a chip, and mountainous seas were threatening to break through the observing domes. Magnetic declinations were observed on all but one day, during the four months' cruise—a remarkable record, considering the prevailing conditions of fog, mist, rain, and snow. This record was made possible only by the constant watchfulness of the entire party and by taking advantage of every opportunity. Considerable time was

spent in "standing by," waiting for a break in the clouds or fog. Frequently only a small opening in the clouds would be seen approaching the Sun; then the vessel would be directed to the proper heading and all observers would be called to their stations ready to begin observations the moment the Sun appeared. Often the Sun was not seen again during the day.

I can not speak too highly of the work done by each and every member of the party, as to spirit of cooperation and unfaltering zeal in the face of most trying conditions.

Gales occurred of force 7 or higher, Beaufort scale, on 52 out of 120 days. On 26 days the gales were very strong, having an estimated force of 9 to 11. We were overtaken by a continual procession of circular storms, moving about the south polar continent from west to east, and were invariably caught in the northern semicircle, as indicated by the barometer changes. A falling barometer always presaged northerly winds shifting to the northwest and blowing hard. As the barometer began to rise, the wind shifted to southwest, blowing a strong gale if the barometer rose rapidly. The temperature of the sea water was taken every hour during the entire cruise, excepting the first few days. The air temperature averaged about 5° C. We had precipitation of some sort, mist, light rain, fog, rain, hail, or snow on 100 days out of the 120 days of the voyage. Fog was recorded on 20 days, and snow 16 days.

We were in the region where icebergs may be encountered for a period of 3½ months, yet saw them on only 24 days, and to the number of only 133, the largest being 5 miles long and the highest being 400 feet high.

Upon the return to Port Lyttelton (April 1), there still remained 2 tanks of fresh water on board, and potatoes and onions sufficient for 3 more weeks.

The vessel sustained no serious damage during the trip. The metal fastening of the upper topsail yard broke on January 4, but the yard was successfully lashed to the parral and gave us no further trouble. The bronze bob-stay carried away at the forward end on February 24. It was fished up after some difficulty and secured with a dead eye and lanyard. Upon examination in the dry dock, the vessel's hull was found absolutely clean and undamaged, only one sheet of copper near the keel requiring renewal.

The total distance run from Lyttelton to Lyttelton was 17,084 miles, giving an average of 145 miles for 118 days. The entire track followed is shown in Figure 14.

ABSTRACTS OF LOGS OF THE CARNEGIE.

W. J. PETERS: ABSTRACT OF LOG, CRUISE I, 1909-1910.

BLOCK ISLAND, RHODE ISLAND, TO ST. JOHN'S, NEWFOUNDLAND.

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1909	° ′	° ′	*miles*	
Sept. 13[1]	Block Island........		....	11h 48m a. m. left Block Island. Calm to gentle westerly breezes. Partly cloudy.
14	40 47 N.	290 05	71	Light breeze from W. to S. and calm. Clear.
15	40 40 N.	290 51	35	Gentle breeze from E. Partly cloudy.
16	40 54 N.	291 34	36	1h 35m a. m. stopped engine. Calm and partly cloudy.
17	41 08 N.	292 45	55	Moderate breeze from S. Partly cloudy.
18	41 57 N.	296 18	167	Moderate northerly breeze. Cloudy.
19	41 49 N.	299 06	125	Fresh northeasterly breeze. Cloudy.
20	42 21 N.	298 42	37	Gentle breeze from E. followed by calm. Clear.
21	42 36 N.	298 53	17	Calm to gentle northwesterly breezes. Clear.
22	43 38 N.	300 40	100	Gentle breeze from NNW. to W. Clear.
23	44 55 N.	303 35	147	Moderate northwesterly breeze. Overcast and foggy with light rain.
24	46 09 N.	306 55	159	Moderate northerly breeze. Overcast and foggy with rain.
25	St. John's		63	10h 30m p. m. anchored in St. John's harbor. Gentle southeasterly breeze. Overcast.

Total distance: 1,012 miles. Time of passage: 12.4 days. Average day's run: 81.6 miles.

[1]The *Carnegie* left Brooklyn August 21, 1909, for trial run and for swings in Gardiners Bay. When these had been completed, she proceeded to Block Island to await a favorable wind.

ST. JOHN'S, NEWFOUNDLAND, TO FALMOUTH, ENGLAND.

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1909	° ′	° ′	*miles*	
Oct. 2	St. John's			10ʰ 12ᵐ a. m. passed out of St. John's Harbor. Light air from WSW. Cloudy.
3	47 58 N.	309 00	71	Light breeze from NW. Overcast and foggy.
4	48 23 N.	312 02	124	Light breeze from NW. Cloudy.
5	48 47 N.	314 01	84	Gentle breeze from SW. Heavy swell from NE. Cloudy.
6	49 12 N.	316 38	106	Moderate gale from WNW. Cloudy with frequent showers.
7	49 31 N.	321 41	198	Moderate gale from WNW. Cloudy. Heavy showers.
8	50 14 N.	326 54	206	Moderate to strong gales from WSW. to W. Squally with heavy sea from W. by S. to W. by N. Cloudy. Heavy showers.
9	50 44 N.	331 45	188	Fresh breeze from W. to WNW. Moderate sea. Cloudy with showers.
10	50 36 N.	337 09	205	Moderate gale from WSW. Heavy squalls of rain and wind. Cloudy.
11	50 23 N.	341 54	182	Fresh breeze from W. Heavy sea from WNW. Heavy squalls. Cloudy with rain. Lightning in E. and SW.
12	50 00 N.	347 02	198	Fresh breeze from W. by N. Squally. Rain.
13	49 25 N.	351 42	185	Stiff breeze from W. Cloudy.
14	Falmouth		158	Moderate breeze from W. 9ʰ 01ᵐ a. m. anchored in Falmouth Bay.

Total distance: 1,905 miles. Time of passage: 12 days. Average day's run: 158.8 miles.

FALMOUTH TO FUNCHAL, MADEIRA.

Date	Lat.	Long.	Day's run	Remarks
1909	° ′	° ′	*miles*	
Nov. 9	Falmouth			Proceeded to Falmouth Bay. Light westerly winds.
10	49 49 N.	354 29	35	7ʰ 43ᵐ a. m. left under sail. 10ʰ 16ᵐ a. m. passed Lizard. Stiff wind NNW.
11	48 51 N.	351 09	141	Stiff to light wind NNW. to NNE.
12	48 36 N.	349 58	49	Weather cloudy. Sea smooth. Light airs from NW. to N.
13	47 44 N.	348 23	81	Light airs from NNW. Overcast; passing showers; calm.
14	46 28 N.	345 41	137	Wind NE. to E.; moderate to stiff. Overcast; passing showers.
15	44 34 N.	344 32	123	Wind NE. to SE. Light breeze to moderate gale. Rough sea.
16	42 17 N.	344 10	136	Moderate to whole gale from SE. quadrant. Rough sea. Sky overcast.
17	41 53 N.	343 38	36	Moderate to fresh gale and high sea from SE. to E. Overcast and rainy.
18	40 34 N.	341 39	120	Stiff to fresh wind from E. to W. Heavy sea from E.
19	40 23 N.	341 57	19	Moderate wind SSE. to SW.
20	40 15 N.	342 05	13	Calm to light airs. Weather cloudy.
21	39 52 N.	342 24	25	Light baffling airs SW. to W. Cloudy weather, with rain and squalls.
22	37 00 N.	343 27	177	Weather clear. Wind westerly; moderate to fresh.
23	35 47 N.	343 35	80	Calm to moderate. Easterly wind. Partly cloudy weather.
24	Funchal		209	7ʰ 25ᵐ p. m. anchored off Funchal.

Total distance: 1,381 miles. Time of passage: 14.5 days. Average day's run: 95.3 miles.

FUNCHAL TO HAMILTON, BERMUDA.

Date	Lat.	Long.	Day's run	Remarks
1909	° ′	° ′	*miles*	
Dec. 1	Funchal			4ʰ 10ᵐ p. m. left Funchal.
2	30 26 N.	341 30	150	Wind easterly. Weather fine.
3	28 01 N.	339 48	167	Moderate wind ENE. Weather fine.
4	26 13 N.	338 35	127	Moderate E. wind. Fine weather.
5	24 35 N.	336 24	152	Moderate E. wind. Fine weather.
6	22 59 N.	334 20	149	Moderate E. wind. Fine weather.
7	21 38 N.	331 40	163	Moderate E. to SE. wind. Fine weather.
8	20 54 N.	328 17	206	Fresh SE. winds.
9	21 05 N.	325 48	136	Mod. SE. winds. Cloudy; long rolling seas; passing showers; blue sky; squally.
10	21 05 N.	324 31	75	Gentle ENE. winds. Blue sky, cloudy; rain squalls.
11	20 50 N.	322 35	109	Moderate NE. wind. Weather fine. Moderate NW. swell.
12	20 38 N.	320 30	121	Moderate NE. to ESE. wind. Weather fine; moderate NNW. swell.
13	20 38 N.	319 14	72	Light E. winds. Fine weather. Moderate northerly swell.
14	20 28 N.	318 01	74	Light airs to gentle breeze NNE. to E. Partly cloudy.
15	19 56 N.	316 30	94	Light N. to NNE. wind. High swell NNW.; cloudy.
16	20 03 N.	314 11	132	Gentle N. to NNE. wind. High swell NNW.; partly cloudy.
17	20 02 N.	312 25	101	Gentle NNE. to E. wind. Swell going down. Partly cloudy.
18	20 01 N.	311 56	31	Light airs and calm; partly cloudy.
19	19 45 N.	311 16	42	Light airs and calm; partly cloudy.
20	19 48 N.	310 18	54	Light airs and calm; partly cloudy.

FUNCHAL TO HAMILTON, BERMUDA—*concluded.*

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1909	° ′	° ′	*miles*	
Dec. 21	19 40 N.	309 54	27	Light airs and calm; partly cloudy. Engine started 9 a. m.; stopped 7 p. m.
22	19 44 N.	309 17	38	Light airs and calm; partly cloudy. Engine started 10 a. m.; stopped 1 p. m.
23	19 54 N.	308 26	51	Light airs and calm; partly cloudy.
24	20 53 N.	306 16	138	Light SE. wind followed by moderate to fresh wind S. to SW.
25	21 46 N.	305 33	66	Wind SW. to NW. High NW. swell. Weather partly cloudy.
26	21 36 N.	305 08	23	Light NNW. breeze to calm. High NW. swell. Weather partly cloudy.
27	22 24 N.	303 39	98	Wind SSE. to SW. Heavy squall of wind and rain from NW.
28	23 02 N.	302 11	90	Heavy squalls of NW. wind and rain. High NW. swell. Wind NE. to SW.
29	23 58 N.	300 35	103	Fine weather; gentle to moderate wind from ESE. to S. High NW. swell.
30	25 14 N.	298 13	153	Moderate to stiff wind SE. to S. Fine weather.
31	25 33 N.	297 35	37	Wind SW. to NNW. Light air to moderate gale. Heavy swell. Weather clear to cloudy.
1910				
Jan. 1	25 50 N.	295 56	93	Heavy NW. swell. Weather clear to cloudy. Light to mod. wind NNW. to NNE.
2	26 46 N.	294 28	96	Moderate to fresh wind NNE. to NE.. Heavy squalls of wind and rain.
3	28 03 N.	293 13	105	Moderate to light NE. wind. Fine weather.
4	28 31 N.	292 46	36	Light breeze from NE. quadrant followed by calm.
5	29 45 N.	292 09	82	Light airs WNW. to NW. followed by moderate gale from NE. with rough sea.
6	31 11 N.	292 22	91	Wind from NE. quadrant shifting to E.
7	Hamilton .	....	190	$12^h 40^m$ p. m. received pilot off Gibb's Hill. 5 p. m. anchored off Ducking Stool.

Total distance: 3,672 miles. Time of passage: 37 days. Average day's run: 99.2 miles.

HAMILTON TO BROOKLYN.

Date	Lat.	Long.	Day's run	Remarks
1910	° ′	° ′	*miles*	
Jan. 28	Hamilton .	....	....	$9^h 30^m$ a. m. left Hamilton.
29	34 59 N.	292 34	234	Wind backs, then blows a gale.
30	35 24 N.	292 41	26	5 p. m. hove to on S. tack. Strong gale from W.
31	36 38 N.	291 39	89	$2^h 30^m$ p. m. wore ship to eastward. Heavy squalls. Min. bar. 753.0.
Feb. 1	37 32 N.	291 08	59	Overcast, rain, long rolling sea and tide rips.
2	36 43 N.	290 34	56	Heavy gale from N.
3	36 10 N.	289 46	50	Wind backing and moderating.
4	37 33 N.	289 26	85	Strong gale from W. to NW. Rough sea.
5	37 15 N.	290 55	73	Gale moderating.
6	36 52 N.	291 04	25	NW. gale, snow and hail. Rough sea.
7	34 41 N.	289 58	102	NW. gale, snow and hail. Rough sea.
8	34 56 N.	289 54	27	Wind and sea moderating.
9	37 07 N.	289 04	135	Moderate to fresh W. to NW. wind.
10	39 05 N.	288 36	123	Moderate gale SW. to NW. Rough sea.
11	40 17 N.	289 06	77	Moderate gale NW. by W., then moderating.
12	40 12 N.	287 10	100	Variable winds. 11 p. m. strong gale E., thick snow.
13	40 19 N.	287 50	72	W. to WNW. wind, moderate to fresh gale varied by calms. 5 p. m. passed Montauk Point.
14	....	....	60	3 a. m. came to anchor N. of Montauk Pt. $8^h 30^m$ hove short. 8 p. m. weighed anchor; $10^h 03^m$ Little Gull Lt.; $11^h 26^m$ Orient Pt.
15	....	....	55	Working towards New Haven. 3 a. m. came to anchor off Clinton, Conn. 10 a. m. weighed anchor; 4 p. m. Heaton's Dock, New Haven.
16	....	....	....	Lying at Heaton's Dock, New Haven, Conn. Head wind.
17	Brooklyn..	....	81	$6^h 41^m$ a. m. left New Haven in tow of tug *Alert;* $5^h 15^m$ p. m. stopped at quarantine. $7^h 30^m$ p. m. docked at Brooklyn.

Total distance: 1,529 miles. Time of passage: 20.4 days. Average day's run: 75.0 miles.

Summary of Passages for Cruise I of the Carnegie.

TABLE 67.

Passage	Length of passage	Time of passage	Average day's run
	miles	*days*	*miles*
Brooklyn to Block Island......	101	....	....
Block Island to St. John's.....	1,012	12.4	82
St. John's to Falmouth........	1,905	12.0	159
Falmouth to Funchal.........	1,381	14.5	95
Funchal to Hamilton.........	3,672	37.0	99
Hamilton to Brooklyn........	1,529	20.4	75

Length of Cruise I: 9,600 miles. Time at sea: 96.3 days. Average day's run: 100 miles.

W. J. PETERS: ABSTRACT OF LOG, CRUISE II, 1910–1913.

GREENPORT, LONG ISLAND, TO PORT MULAS, VIEQUES.

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1910	° ′	° ′	*miles*	
June 29[1]	Greenport	....	....	$2^h 45^m$ p. m. left Greenport under power and sail. $4^h 45^m$ p. m. stopped engine. Moderate breeze from W.
30	40 53 N.	289 08	34	Calm to moderate SW. breeze. Sea smooth. Lightning during evening.
July 1	40 00 N.	292 06	146	Gentle breeze from SW. to NW. and calm. Sea smooth. Gulf Stream.
2	39 42 N.	294 39	118	Moderate breeze from SW. Sea moderate, increasing.
3	37 52 N.	296 18	166	Stiff breeze from NW. to SW. Sea choppy.
4	37 56 N.	299 06	86	Moderate breeze from SW. Sea choppy to rough. Left Gulf Stream.
5	38 12 N.	303 26	206	Stiff breeze from SW. and SW. by W. Heavy sea. Rain and wind squalls.
6	38 12 N.	307 16	182	Stiff to light breeze, SW. to NNW. to NNE. Rainy and squally to clear.
7	37 56 N.	309 26	103	Light breeze from NE. to NW. to NNE.
8	37 59 N.	310 48	65	Light variable airs and calm. Moderate swell.
9	37 03 N.	311 53	76	Gentle breeze from W. to SW. Smooth sea.
10	35 57 N.	312 53	81	Gentle breeze from SW. to S. and calm. Sea smooth.
11	35 33 N.	313 02	25	Light variable breezes and calm. Sea smooth.
12	34 48 N.	313 17	47	Calm. Sea smooth.
13	33 53 N.	313 59	66	Variable breezes. Sea smooth.
14	33 09 N.	314 08	44	Wind variable, and calm. Sea smooth. $3^h 15^m$ p. m. started engine.
15	31 05 N.	314 02	124	Wind variable, and calm. Sea smooth.
16	29 47 N.	313 52	79	Wind variable, and calm. Caught NE. trades. $12^h 05^m$ a. m. engine stopped; $4^h 55^m$ p. m. started; midnight, stopped.
17	28 10 N.	313 35	98	Gentle SE. breeze.
18	25 39 N.	312 02	172	Moderate breeze from ESE. to E.
19	23 27 N.	309 23	196	Stiff breeze from E.
20	21 48 N.	306 30	187	Stiff breeze from E.
21	20 24 N.	303 51	171	Moderate breeze from E. by N.
22	19 13 N.	301 07	170	Moderate breeze from ENE.
23	18 49 N.	297 59	180	Stiff breeze from NE. to ENE.
24	Port Mulas	....	194	Stiff breeze from E. by N. to E. by S. $2^h 05^m$ p. m. anchored at Port Mulas.

Total distance: 3,016 miles. Time of passage: 25 days. Average day's run: 120.6 miles.

[1]The *Carnegie* left Brooklyn, June 20, to make swings in Gardiners Bay and for final preparations before going to sea, usually anchoring off Greenport.

VIEQUES AND SAN JUAN TO PARA.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1910	° ′	° ′	*miles*	
July 27	Port Mulas	....	12	$7^h 17^m$ a. m. proceeded from Port Mulas under sail. Fresh easterly breeze. $8^h 35^m$ p. m. anchored in Target Bay.
Aug. 1	Target Bay	....	12	Left 11 a. m. under sail. Mod. breeze, ENE. $2^h 40^m$ p. m. arrived Port Mulas.
5	Port Mulas	....	12	Left $6^h 15^m$ a. m. under sail. Mod. breeze, ENE. $4^h 50^m$ p. m. arrived Target Bay.
7	Target Bay	....	56	$6^h 45^m$ a. m. left Target Bay under sail. Moderate northeasterly breeze. $5^h 20^m$ p. m. arrived at San Juan. Sea smooth.
18	San Juan	....	38	Left 7 a. m. under engine-power. Mod. breeze, ENE. 8 a. m. stopped engine.
19	22 11 N.	192 58	193	Moderate breeze from ENE.
20	24 55 N.	193 36	168	Fresh breeze from E. by S.
21	27 43 N.	194 40	178	Fresh breeze from E. by S.
22	30 23 N.	196 34	189	Moderate to fresh breeze from SE. by E.
23	32 43 N.	198 17	165	Moderate breeze from SE. to calm.
24	33 14 N.	298 39	37	Light airs and calm.
25	33 04 N.	300 39	101	Gentle to fresh breeze from NNE. Sea moderate.
26	32 51 N.	303 39	152	Gentle to fresh breeze from NE. Sea moderate. Squalls.
27	32 26 N.	304 59	72	Calm and light airs. Squalls. Long SE. swell.
28	32 30 N.	305 41	36	Calm and light airs. Squalls. Long NE. swell.
29	32 21 N.	305 52	13	$3^h 10^m$ p. m. started engine; 8 p. m. stopped engine. Calm.
30	31 54 N.	307 16	76	$7^h 55^m$ a. m. started engine; $4^h 18^m$ p. m. stopped. Light air.
31	30 58 N.	308 37	89	Light airs to fresh breeze.
Sept. 1	28 40 N.	312 11	227	Fresh breeze WSW. to NE. Sea choppy.
2	27 43 N.	313 33	96	Light airs to moderate breeze.
3	26 11 N.	314 00	95	Calm to moderate ESE. breeze. Caught trades.
4	24 08 N.	314 34	133	Moderate breeze from ESE.
5	22 03 N.	315 38	134	Moderate breeze from E.
6	19 48 N.	317 02	155	Moderate breeze from E.
7	17 26 N.	318 22	161	Moderate breeze from ENE. Squalls.
8	15 24 N.	319 36	141	Moderate breeze from ENE. Squalls.

VIEQUES AND SAN JUAN TO PARA—*concluded.*

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1910	° ′	° ′	*miles*	
Sept. 9	14 37 N.	320 13	58	Variable breezes to calm. Long NE. swell.
10	12 10 N.	320 36	149	Variable breezes. Squalls. Tide rips.
11	10 27 N.	320 43	103	$2^h 38^m$ p. m. started engine; 12 p. m. stopped. Calm. Long NE. swell.
12	9 13 N.	321 38	92	$8^h 40^m$ a. m. started engine; 8 p. m. stopped. Calm. Long NE. swell.
13	8 08 N.	322 29	82	1 p. m. started engine; 8 p. m. stopped.
14	7 13 N.	323 06	67	$9^h 45^m$ a. m. started engine; 6 p. m. stopped.
15	6 41 N.	323 12	33	Light variable airs. Sea smooth.
16	6 17 N.	323 17	24	Light variable airs. Sea smooth.
17	5 52 N.	324 06	55	Light variable airs and calm. Sea smooth.
18	5 36 N.	324 12	17	Calm to moderate breeze from S. by E. Caught SE. trade.
19	3 33 N.	322 18	168	Gentle breeze from SE. Sea smooth.
20	2 04 N.	320 13	154	Gentle breeze from SSE. Sea smooth.
21	0 47 N.	317 02	206	Gentle breeze from S. by E.
22	0 00	314 07	189	Gentle easterly breeze. Sea choppy. On soundings.
23	0 24 S.	312 03	138	Gentle easterly breeze. Sea choppy. On soundings. Off Para Mouth.
24	Para......	....	73	Gentle breeze from NE. To anchorage off Jetuba I. $12^h 23^m$ a. m. anchored. $5^h 56^m$ a. m. left anchorage. $10^h 10^m$ a. m. anchored off City of Para.

Total distance: 4,257 miles. Time of passage: 37.1 days. Average day's run: 114.7 miles.

PARA TO RIO DE JANEIRO.

Date	Lat.	Long.	Day's run	Remarks
1910	° ′	° ′	*miles*	
Oct. 15	Para......	....	......	$10^h 35^m$ p. m. left Para (Pinheiro Pt.). Working out of river under power.
16	....	....	......	$9^h 30^m$ p. m. left Gairotas Anchorage under power and sail. $11^h 55^m$ p. m. left river.
17	0 53 N.	311 51	89	$1^h 40^m$ a. m. stopped engine. Proceeded under sail. Moderate breeze from E.
18	4 05 N.	311 12	196	Moderate sea. Fresh breeze from ENE.
19	6 05 N.	311 12	120	Moderate sea. Gentle breeze from ENE.
20	6 51 N.	311 45	56	Made colors to Brasilian man-of-war bound E. Calm. Heavy SE. swell.
21	6 02 N.	312 29	74	Moderate sea. Calm to light breeze from SSE.
22	7 23 N.	314 08	128	Moderate sea. Moderate southeasterly breeze.
23	10 10 N.	314 09	166	Moderate sea. Moderate easterly breeze.
24	12 00 N.	314 16	111	Smooth sea. Gentle easterly breeze.
25	13 09 N.	314 25	70	Moderate sea. Moderate breeze from ESE.
26	15 17 N.	315 39	146	Moderate sea. Moderate breeze from ESE.
27	18 04 N.	316 23	173	Smooth sea. Moderate breeze from E. by S.
28	17 28 N.	317 03	53	Moderate sea. Fresh easterly breeze.
29	15 23 N.	318 11	141	Rough sea. Moderate breeze from E. by S.
30	13 09 N.	318 51	139	Moderate sea. Heavy current rips. Moderate breeze from E. by S.
31	11 21 N.	319 17	115	$5^h 37^m$ p. m. started engine. Current rips. Gentle breeze from ESE. 8 p. m. stopped engine. Squally, variable winds.
Nov. 1	12 02 N.	320 20	74	$8^h 50^m$ a. m. started engine; $6^h 50^m$ p. m. stopped engine. Long easterly swell. Variable breezes.
2	12 07 N.	321 15	54	$8^h 25^m$ a. m. started engine; 8 p. m. stopped it. Smooth sea, current rips. Calm.
3	11 50 N.	322 05	52	$8^h 55^m$ a. m. started engine. $5^h 05^m$ p. m. stopped engine. Smooth sea, squally. Gentle breeze from E.
4	12 30 N.	322 32	48	Smooth sea. Gentle breeze from E. by N.
5	10 58 N.	323 02	97	Moderate SE. swell. Gentle easterly breeze.
6	11 09 N.	323 25	25	Smooth sea, variable winds.
7	11 52 N.	323 58	54	Squally, variable breezes, smooth sea.
8	11 42 N.	324 04	12	Squally. Variable breezes. Long swell from S.
9	10 47 N.	324 32	62	Squally. Long swell from S. Moderate breeze from SE. by E.
10	10 14 N.	325 07	48	Squally. Fresh breeze from E. by N. Choppy sea, and long swell from S.
11	8 14 N.	325 52	128	Squally. Moderate breeze E. by S. Rough sea, waterspout passed near.
12	6 26 N.	326 31	115	Squally. Confused sea. Variable breezes.
13	6 45 N.	327 03	38	Squally. Confused sea. Variable winds.
14	5 43 N.	327 39	71	Squally. Confused sea. Variable winds.
15	3 53 N.	327 51	111	Squally. Rough sea. Variable winds.
16	3 22 N.	328 00	32	Squally. Rough sea. Variable winds.
17	1 28 N.	327 13	123	Squally. Rough sea. Caught SE. trades.
18	1 11 S.	326 02	173	Moderate sea. Crossed the equator. Fresh southeasterly breeze.
19	4 01 S.	325 32	174	Heavy to moderate sea. Fresh southeasterly breeze.
20	5 23 S.	325 27	82	Long SE. swell. Sighted Brasilian coast near Natal. Fresh SE. breeze.
21	6 00 S.	325 36	38	Rough sea. Fresh breeze from SE. by S. Squally. Beating down coast.

PARA TO RIO DE JANEIRO—*concluded.*

Date	Noon position Lat.		Long. E. of Gr.		Day's run	Remarks
1910	°	′	°	′	*miles*	
Nov. 22	7	41 S.	325	21	101	Long SE. swell. Passed Pernambuco. Moderate breeze from SE. by S. Beating down coast.
23	9	55 S.	325	24	134	Passed Cape St. Augustine. Moderate swell. Squally. Fresh ESE. breeze.
24	12	56 S.	324	46	185	Moderate breeze from E. by S. Moderate sea.
25	15	15 S.	323	59	166	Fresh breeze from SE. Moderate sea.
26	17	45 S.	323	12	156	Gentle breeze from ENE. Moderate swell.
27	19	27 S.	322	15	114	Gentle breeze from NE. by E. Moderate swell.
28	21	20 S.	321	02	132	Gentle breeze from NNE. Moderate swell.
29	21	53 S.	320	15	55	6 p. m. lay to. Moderate gale from SW. Rough sea.
30	22	26 S.	321	02	55	Lying to till 9 a. m. Rough sea. Strong breeze from S.
Dec. 1	23	03 S.	319	22	100	Reaching till 4 a. m. Long swell. Gentle breeze from S.
2	Rio de Janeiro.......				147	1ʰ 55ᵐ p. m. till 6ʰ 15ᵐ p. m. under power. Long swell. Calm and variable winds. 6ʰ 15ᵐ p. m. arrived at Rio de Janeiro.

Total distance: 4,733 miles. Time of passage: 47.8 days. Average day's run: 99.0 miles.

RIO DE JANEIRO TO MONTEVIDEO.

Date	Lat.		Long.		Day's run	Remarks
1910	°	′	°	′	*miles*	
Dec. 29	Rio de Janeiro.......				....	6ʰ 42ᵐ p. m. left Rio de Janeiro under power.
30	23	56 S.	317	01	55	4ʰ 14ᵐ a. m. stopped engine.
31	24	13 S.	316	42	21	Long SE. swell, squally. Gentle southerly breeze.
1911						
Jan. 1	25	04 S.	317	05	56	Long swell from S., squally. Gentle westerly breeze.
2	26	36 S.	318	03	106	Long swell from SW. Gentle breeze, SW.
3	26	52 S.	317	36	30	Light airs from SW.
4	28	11 S.	316	08	111	Gentle breeze from ENE.
5	30	09 S.	315	17	126	Moderate westerly breeze.
6	30	47 S.	314	30	56	Moderate breeze, W. by S.
7	30	27 S.	312	51	84	Gentle southwesterly breeze.
8	30	22 S.	312	21	27	Long NE. swell. Light airs from ENE. 12ʰ 55ᵐ p. m. started engine; 11ʰ 25ᵐ p. m. stopped.
9	31	16 S.	312	02	57	Moderate southerly breeze.
10	31	29 S.	312	14	17	Long SW. swell. Calm.
11	33	23 S.	310	31	144	Moderate breeze, NE.
12	34	29 S.	307	56	148	Long NE. swell. On soundings. Gentle breeze, ENE.
13	35	01 S.	305	56	104	Long easterly swell. Off Cape Santa Maria. Under power. Variable breezes.
14	Montevideo				116	11ʰ 05ᵐ a. m. anchored, Montevideo. Left Jan. 16, arrived Buenos Aires 17th.

Total distance: 1,258 miles. Time of passage: 15.7 days. Average day's run: 80.1 miles.

MONTEVIDEO TO CAPE TOWN.

Date	Lat.		Long.		Day's run	Remarks
1911	°	′	°	′	*miles*	
Feb. 14	Buenos Aires.......				....	9ʰ 40ᵐ a. m. left Buenos Aires in tow. 5ʰ 20ᵐ p. m. anchored off La Plata.
15	La Plata...........				....	1ʰ 30ᵐ a. m. left anchorage. 11 a. m. anchored near Cuirassier Bank.
16	Cuirassier Bank				....	Remained at anchor.
17	Cuirassier Bank				....	Remained at anchor.
18	Cuirassier Bank				....	4 a. m. left anchorage; 5ʰ 20ᵐ p. m. anchored off Panuela Rock.
19	Panuela Rock.......				....	Remained at anchor.
20	Montevideo.........				....	7ʰ 45ᵐ a. m. left anchorage at Panuela Rock; 6ʰ 40ᵐ p. m. anchored.
21	35	39 S.	304	04	47	2ʰ 50ᵐ a. m. left anchorage at Montevideo, proceeded to sea. Light airs, N.
22	36	22 S.	305	46	93	Light airs, NW. Fine weather.
23	36	04 S.	307	50	103	Gentle SE. breeze. Fine weather.
24	36	16 S.	308	18	25	Light airs from E. Long swell. Fine weather.
25	36	28 S.	309	36	63	Gentle breeze, NNE. Fine weather.
26	37	34 S.	312	20	146	Moderate NE. breeze. Fine weather.
27	38	32 S.	315	21	154	Strong breeze, NE. by N. Rough sea. Cloudy weather.
28	39	12 S.	319	08	181	Moderate gale, N. by E. Rough sea. Cloudy and misty weather.
Mar. 1	39	28 S.	322	00	135	Calm. Choppy sea. Cloudy and misty weather.
2	39	40 S.	324	31	116	Moderate gale, S. by W. Rough sea. Cloudy and squally.
3	39	56 S.	328	02	162	Fresh breeze, SSW. Long heavy swell. Cloudy weather.
4	40	37 S.	331	51	180	Fresh breeze, SSW. Long heavy swell. Overcast.
5	40	37 S.	334	32	125	Variable airs. Cloudy weather.
6	40	50 S.	336	48	104	Moderate NE. breeze. Overcast and rainy. Gale.

MONTEVIDEO TO CAPE TOWN—*concluded.*

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1911	° ′	° ′	*miles*	
Mar. 7	41 22 S.	340 01	149	Moderate breeze, WNW. Heavy sea. Fog.
8	41 16 S.	344 03	182	Moderate breeze from N. Fog.
9	41 01 S.	348 41	210	Fresh breeze from N. Fog.
10	40 45 S.	352 41	176	Gentle southerly breeze. Fog.
11	40 54 S.	354 18	74	Moderate westerly breeze. Smooth sea. Fine weather.
12	39 56 S.	358 08	185	Fresh breeze, SW. Fine weather to squally.
13	39 29 S.	0 39	120	$8^h 50^m$ a. m. started engine. Long swell. Light airs from SW. $9^h 40^m$ a. m. stopped engine.
14	39 23 S.	2 02	65	Gentle breeze, N. by E. Long swell. Cloudy.
15	39 06 S.	4 29	115	Light breeze, NNE. Cloudy.
16	38 27 S.	7 20	139	Moderate northerly breeze. Smooth sea. Fine weather.
17	37 58 S.	9 37	112	Gentle breeze, NNW. Confused sea. Fine weather.
18	36 56 S.	11 47	122	Light breeze, WNW. Fine weather.
19	35 19 S.	15 53	222	Strong breeze, SSW. Overcast. Rough sea.
20	Cape Town	....	154	$2^h 30^m$ p. m. arrived at Cape Town. Light variable airs.

Total distance: 3,659 miles. Time of passage: 27.5 days. Average day's run: 133.1 miles.

CAPE TOWN TO COLOMBO, CEYLON.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1911	° ′	° ′	*miles*	
Apr. 26	Cape Town	....	....	Left Cape Town, $1^h 30^m$ p. m.
27	35 48 S.	20 07	170	Rough sea, cloudy. Strong breeze, WSW.
28	37 25 S.	23 44	202	Rough sea, cloudy. Moderate gale from NW.
29	38 29 S.	27 18	180	Rough sea, cloudy. Moderate northerly breeze.
30	40 04 S.	30 20	171	Long swell, foggy. Gentle breeze, NNW.
May 1	40 22 S.	33 33	146	Cross sea, overcast, cloudy and hazy. Moderate breeze, NE. by N.
2	40 17 S.	37 04	154	Cloudy. Moderate breeze, S. by E.
3	39 46 S.	38 16	64	Large school of blackfish about the ship. Calm.
4	40 14 S.	41 44	161	Cloudy. Strong breeze, S. by W.
5	38 39 S.	44 19	154	Rough sea, cloudy and hazy. Strong SW. breeze.
6	39 04 S.	47 27	148	Rough sea, cloudy and overcast. Fresh westerly breeze.
7	39 11 S.	51 45	201	Heavy sea, cloudy. Gale blowing from SW.
8	39 21 S.	55 05	155	Rough sea, cloudy and squally. Strong breeze from W.
9	40 02 S.	58 55	181	Partly cloudy. Fresh breeze, WSW.
10	40 18 S.	62 41	174	Moderate breeze, WNW. Fine weather.
11	40 19 S.	67 41	230	Rough sea, cloudy and squally. Moderate gale blowing from WSW.
12	39 40 S.	71 08	163	Cloudy and squally. Moderate breeze, S. by E.
13	39 16 S.	72 15	58	Smooth sea, cloudy. Gentle breeze from WNW.
14	39 26 S.	73 52	76	Smooth sea, partly cloudy. Swung ship. Gentle NE. breeze.
15	40 12 S.	74 25	52	Long swell, partly clear. Gentle breeze, ESE.
16	38 58 S.	75 31	89	Long easterly swell, cloudy. Gentle breeze SSE.
17	38 43 S.	77 21	87	Long swell, cloudy to clear. Off St. Paul I. Gentle breeze, WSW.
18	37 56 S.	77 43	70	Rough sea, squally. Moderate gale blowing from WNW. Off Amsterdam I.
19	35 25 S.	77 38	151	Long swell, cloudy. Light breeze, SSW.
20	33 54 S.	78 01	92	Long swell, cloudy. Swung ship. Gentle breeze WSW.
21	31 43 S.	77 32	134	Cloudy and squally. Moderate breeze, S. by E.
22	28 09 S.	76 54	217	Caught SE. trades. Strong breeze, E. by N.
23	25 50 S.	76 20	142	Rough sea, overcast and squally. Strong breeze from E.
24	23 38 S.	76 22	132	Cloudy and squally. Moderate breeze, SE. by E.
25	20 47 S.	76 32	172	Passing showers. Moderate SE. breeze.
26	19 09 S.	76 17	98	Smooth sea, clear. Light variable airs.
27	18 18 S.	76 22	51	Smooth sea, passing showers. Gentle breeze, SSW.
28	15 22 S.	76 10	176	Partly cloudy. Fresh SE. breeze.
29	12 18 S.	75 48	186	Partly cloudy. Strong breeze, SE. by E.
30	10 06 S.	75 48	131	Partly cloudy. Gentle breeze, SE. by E.
31	7 25 S.	75 55	162	Partly cloudy. Fresh breeze, SSE.
June 1	5 10 S.	75 40	136	Smooth sea, partly cloudy. Swung ship. Gentle breeze, SSW.
2	2 46 S.	76 16	148	Partly cloudy. Moderate SW. breeze.
3	0 21 N.	76 19	187	Partly cloudy. Moderate breeze, WSW.
4	2 06 N.	77 06	116	Confused sea, cloudy and squally. Gentle breeze, WSW.
5	3 10 N.	77 08	64	Confused sea, cloudy and squally. Light breeze from WSW.
6	4 56 N.	77 52	114	Fine weather. Moderate breeze, SW. by W.
7	Colombo..	....	175	Fine weather. Arrived Colombo 7 p. m.

Total distance: 5,870 miles. Time of passage: 42.2 days. Average day's run: 139.1 miles.

COLOMBO, CEYLON, TO PORT LOUIS, MAURITIUS.

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1911	° ′	° ′	*miles*	
July 6	Colombo..	....	......	Left Colombo 6h 30m p. m. Cloudy. Moderate breeze, SW.
7	7 12 N.	79 14	38	Moderate sea, cloudy, squally. Moderate breeze, WSW.
8	5 05 N.	79 51	132	Moderate sea. Light breeze, SW. by W.
9	3 45 N.	81 21	127	Moderate sea. Moderate breeze, SW. by S.
10	1 59 N.	83 09	145	Moderate sea. Gentle breeze, SW. by S.
11	1 03 N.	84 39	106	Smooth sea. Gentle breeze from SSW.
12	0 57 N.	85 14	36	Smooth sea. Light variable airs.
13	1 13 N.	83 59	78	Smooth sea. Light variable breezes.
14	1 04 N.	84 55	57	Smooth sea. Light breeze from SSW.
15	0 29 N.	86 00	74	Smooth sea. Light breeze, SW. by S.
16	0 07 S.	86 46	59	Smooth sea. Crossed equator. Light breeze, SW. by S.
17	1 37 S.	87 18	95	Long southerly swell. Light breeze from WSW.
18	3 10 S.	88 00	102	Long southerly swell. Calm and light variable airs.
19	4 10 S.	87 54	60	Moderate sea, cloudy, squally. Gentle SE. breeze.
20	5 26 S.	87 04	90	Moderate sea, overcast, showers. Calm to gentle breeze from ESE.
21	7 06 S.	86 22	110	Moderate sea. Cloudy. Caught SE. trades. Moderate breeze from SSE.
22	9 22 S.	84 38	171	Moderate sea. Cloudy. Strong SE. breeze.
23	11 34 S.	82 30	183	Rough sea. Cloudy. Passed tree trunk 50 ft. long, 6 ft. in diameter. Moderate gale blowing from SE. by S.
24	13 16 S.	80 31	155	Rough sea. Cloudy. Moderate SE. gale.
25	15 29 S.	78 43	169	Rough sea. Moderate gale, SE. by S.
26	17 17 S.	76 46	155	Rough sea. Moderate SE. gale.
27	18 46 S.	74 30	158	Rough sea. Strong breeze from SE. by S.
28	20 30 S.	72 05	172	Moderate sea. Moderate breeze, S. by E.
29	21 53 S.	70 04	140	Moderate sea. Fresh breeze from SE. by S.
30	23 25 S.	67 57	150	Long southerly swell. Gentle breeze from S.
31	24 08 S.	65 35	137	Smooth sea. Light breeze from S. by E.
Aug. 1	25 42 S.	63 42	139	Smooth sea. Gentle SE. breeze.
2	25 48 S.	60 56	149	Moderate sea. Moderate breeze, ESE.
3	24 36 S.	58 03	172	Moderate sea. Fresh breeze, ESE.
4	22 24 S.	57 48	133	Moderate sea. Moderate breeze from E.
5	Port Louis.	....	174	Moderate sea. Arrived at Port Louis, Mauritius, 5h 35m p. m.

Total distance: 3,666 miles. Time of passage: 30 days. Average day's run: 122.2 miles.

PORT LOUIS, MAURITIUS, TO COLOMBO, CEYLON.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1911	° ′	° ′	*miles*	
Aug. 16	Port Louis.	....	......	Left Port Louis 4 p. m. Light easterly breeze.
17	18 29 S.	56 40	101	Clear. Gentle breeze, SSE.
18	15 50 S.	55 23	175	Partly cloudy. Moderate breeze from SSE.
19	12 49 S.	54 09	195	Cloudy. Fresh breeze from SSE.
20	9 25 S.	53 01	214	Cloudy, rough sea. Strong breeze, S. by E.
21	6 37 S.	51 54	180	Cloudy. Moderate breeze from S.
22	5 56 S.	51 25	50	Partly cloudy. Gentle breeze, E. by N.
23	2 57 S.	51 54	182	Partly cloudy. Moderate breeze, E. by S.
24	0 28 S.	52 28	152	Cloudy. Moderate SSE. breeze.
25	1 53 N.	53 07	146	Cloudy, smooth sea. Crossed equator. Gentle SE. breeze.
26	3 14 N.	53 36	87	Partly cloudy. Gentle SW. breeze.
27	4 32 N.	54 37	98	Partly cloudy. Light breeze, S. by W.
28	7 10 N.	54 43	159	Partly cloudy. Moderate breeze, SW. by W.
29	10 17 N.	56 22	211	Clear. Rough sea. Strong SW. breeze.
30	11 13 N.	59 16	180	Cloudy. Rough sea. Strong SW. breeze.
31	10 50 N.	62 54	215	Partly cloudy. Moderate SW. breeze.
Sept. 1	10 15 N.	65 46	174	Partly cloudy. Light breeze from WSW.
2	12 51 N.	66 45	166	Partly cloudy. Moderate breeze from W.
3	15 48 N.	67 08	179	Partly cloudy. Gentle breeze from WSW.
4	13 09 N.	69 10	200	Partly cloudy. Moderate breeze, WSW.
5	10 30 N.	70 52	188	Partly cloudy. Gentle breeze from WNW.
6	9 12 N.	72 42	132	Partly cloudy. Gentle NW. breeze.
7	8 13 N.	74 36	127	Partly cloudy. Gentle breeze, NW. by N.
8	7 41 N.	76 29	115	Partly cloudy. Smooth sea. Light breeze from WNW.
9	7 13 N.	78 18	112	Overcast. Smooth sea. Light breeze, W. by S.
10	Colombo..	....	92	Arrived at Colombo 5h 42m a. m.

Total distance: 3,830 miles. Time of passage: 24.6 days. Average day's run: 155.7 miles.

COLOMBO, CEYLON, TO BATAVIA, JAVA.

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1911	° ′	° ′	*miles*	
Sept. 15	Colombo..	....	....	Left Colombo 4h 30m p. m. Gentle breeze, WSW.
16	6 37 N.	79 44	20	Moderate breeze, SW. by S. Cloudy. Beating.
17	6 56 N.	82 28	218	Cloudy. Strong SW. Monsoon. Rough sea.
18	8 31 N.	83 35	115	Cloudy. Moderate breeze, NW. by W.
19	10 49 N.	84 27	148	Cloudy. Moderate breeze from WNW.
20	13 13 N.	84 44	144	Overcast, rainy. Strong breeze from W.
21	14 36 N.	85 01	85	Overcast, rainy, squally. Strong breeze from WSW.
22	15 53 N.	85 27	81	Overcast, rainy, squally. Rough sea. Fresh NW. breeze.
23	13 18 N.	87 03	181	Cloudy, hazy. Moderate gale blowing from SW. Heavy sea.
24	11 43 N.	89 21	165	Cloudy. Moderate breeze, SW. by S.
25	10 11 N.	91 37	162	Partly cloudy. Light SW. breeze.
26	9 24 N.	93 06	100	Partly cloudy. Long SW. swell. Gentle breeze SW. by S.
27	8 55 N.	94 02	63	Partly cloudy. Smooth sea. Light airs from WSW.
28	8 19 N.	95 37	101	Partly cloudy. Smooth sea. Gentle breeze from SSW.
29	6 38 N.	97 48	163	Partly cloudy, hazy. Smooth sea, tide rips. Gentle westerly breeze.
30	6 30 N.	98 27	40	Partly cloudy, hazy. Smooth sea. Light variable airs.
Oct. 1	5 46 N.	99 29	75	Partly cloudy. Smooth sea. Light breeze, NW. by W.
2	4 13 N.	100 04	100	Cloudy. Smooth sea. Light breeze, NE. by E.
3	2 48 N.	101 06	112	Cloudy. Smooth sea. Moderate breeze from WNW.
4	2 17 N.	101 34	60	Partly cloudy. Smooth sea. Light airs from WSW.
5	1 34 N.	103 00	78	Partly cloudy. Smooth sea. Passing showers. Gentle WSW. breeze.
6	1 13 N.	103 54	63	Anchored 7h 30m p. m. Singapore Strait. Light variable breezes.
7	1 13 N.	104 01	6	Up anchor 7h 30m a. m. Anchored 3h 50m p. m. Light variable airs.
8	1 13 N.	104 07	5	Up anchor noon. Anchored 2 p. m. Rhio Strait.
9	0 59 N.	104 11	12	Up anchor 8 a. m. Anchored 11h 15m a. m. Rhio Strait. Calm.
10	0 51 N.	104 18	10	Up anchor 6 a. m. Anchored 1 p. m. Rhio Strait. Calm. Up anchor 10 p. m.
11	0 46 N.	104 23	10	Anchored 5h 30m a. m. Up anchor 11h 15m a. m. Anchored 6h 15m p. m. Light variable airs.
12	0 44 N.	104 24	12	Up anchor 1 p. m. Anchored 4h 15m p. m. Light variable airs.
13	0 41 N.	104 36	2	Up anchor 8 a. m. Anchored 12h 50m p. m. Up anchor 5h 15m p. m. Calm.
14	0 32 N.	104 37	10	Working out of Rhio Strait.
15	0 07 N.	104 56	31	Anchored 9 p. m. off Singa Island. Light breeze, SW. by S.
16	0 03 N.	105 00	6	At anchor, overhauling engine. Gentle breeze from SSW.
17	0 03 N.	105 00	....	At anchor, overhauling engine. Moderate breeze from SSW.
18	0 04 S.	105 08	12	Up anchor 8h 40m a. m. Anchored 4h 45m p. m. Light breeze, SSW.
19	0 06 S.	105 00	9	Anchored off Singa Island.
20	0 27 S.	105 05	22	Up anchor 7h 30m a. m. Anchored 3h 05m p. m. Gentle breeze from W.
21	0 58 S.	104 53	26	Up anchor 7h 15m a. m. Anchored 6h 25m p. m. Moderate breeze, NW. by W.
22	1 48 S.	104 55	50	Up anchor 10h 45m a. m. Entered Banka Strait. Moderate breeze, N. by W.
23	3 21 S.	106 29	152	Cloudy. Passed through Banka Strait. Variable breezes.
24	4 06 S.	106 23	46	Partly cloudy, smooth sea.
25	5 03 S.	106 27	57	Partly cloudy, smooth sea. Light variable airs.
26	5 18 S.	106 54	29	Partly cloudy, squally, smooth sea. Calm to variable breezes.
27	Batavia...	....	52	Partly cloudy. Arrived Tanjong Priok, Batavia, 11h 55m a. m.

Total distance: 2,833 miles. Time of passage: 41.8 days. Average day's run: 67.8 miles.

BATAVIA TO MANILA, PHILIPPINE ISLANDS.

1911	° ′	° ′	*miles*	
Nov. 21	Batavia...	....	10	Left Batavia Roads 6h 45m a. m. Anchored 11h 30m a.m. Variable airs.
22	5 55 S.	106 41	7	Left anchorage 6h 08m a. m. At 8 p. m. anchored. Variable airs.
23	5 59 S.	105 56	49	Left anchorage 5h 20m a. m. In Sunda Strait. Variable airs.
24	6 43 S.	104 50	90	Cloudy, squally. Long southerly swell. Gentle breeze, WNW.
25	8 51 S.	105 46	140	Cloudy, overcast, heavy rain squalls. Moderate breeze, WSW.
26	9 37 S.	106 32	65	Partly cloudy. Moderate NW. swell. Light breeze, WNW.
27	11 07 S.	106 00	96	Partly cloudy, squally. Light variable airs.
28	11 54 S.	105 41	51	Partly cloudy, moderate SE. swell. Calm and light airs.
29	12 38 S.	104 58	60	Overcast, squally, moderate SE. swell.
30	15 40 S.	102 19	238	Partly cloudy. Fresh SE. trades.
Dec. 1	18 28 S.	99 57	220	Partly cloudy. Fresh SE. trades.
2	20 44 S.	97 09	209	Partly cloudy. Fresh SSE. trades.
3	23 16 S.	94 33	208	Cloudy. Fresh SE. by S. trades.
4	25 50 S.	92 13	200	Cloudy. Moderate breeze, SSE.
5	28 21 S.	90 07	189	Cloudy. Gentle breeze, SSE.

BATAVIA TO MANILA, PHILIPPINE ISLANDS—*concluded.*

Date	Noon position Lat.		Long. E. of Gr.		Day's run	Remarks
1911	°	′	°	′	*miles*	
Dec. 6	29	28 S.	89	29	74	Partly cloudy. Moderate swell. Calm and light airs from NNE.
7	30	47 S.	89	23	78	Partly cloudy. Smooth sea.
[illegible]	33	18 S.	89	42	153	Partly cloudy, hazy, damp. Moderate breeze, N. by W.
9	35	24 S.	92	22	183	Partly
[illegible]	37	23 S.	95	[illegible]	194	Overca Long westerly swell.
[illegible]	36	01 S.	97	34	126	Partly ight airs from S.
12	35	03 S.	99	29	110	Partly
13	32	36 S.	101	56	190	Clear.
[illegible]	30	50 S.	103	16	126	Cloudy
15	28	38 S.	104	11	141	Cloudy. Gentle breeze from SSW.
16	25	52 S.	105	32	181	Cloudy. Strong SSE. trades.
17	21	54 S.	106	49	248	Cloudy. Strong SE. trades. Rough SE. sea.
18	19	01 S.	108	11	185	Partly cloudy, breeze.
19	17	10 S.	108	47	120	Partly cloudy. airs from SSW.
20	15	54 S.	109	22	84	Partly Gentle breeze, SSE.
21	14	25 S.	110	29	110	Partly Gentle breeze, SW. by S.
22	13	03 S.	111	28	100	Overca Gentle SW. breeze.
23	11	32 S.	112	49	121	Partly cloudy. Gentle SW. breeze.
24	10	08 S.	114	00	[illegible]	Clear. Gentle SW. breeze.
25	8	58 S.	116	11	142	Partly cloudy. Strait.
26	8	03 S.	116	53	79	breezes.
27	6	41 S.	119	[illegible]	174	h sea. breeze.
28	5	38 S.	120	06	78	th sea. m. Gentle breeze SSW.
29	5	36 S.	120	14	10	mooth sea. Calm.
30	5	42 S.	121	06	56	Calm
31	5	48 S.	122	28	80	variable airs.
1912						
Jan. 1	4	42 S.	123	29	100	Cloudy. Smooth through Buton Passage.
2	3	40 S.	123	42	64	Cloudy. Smooth sea.
3	2	57 S.	124	15	54	Cloudy, squally. Smooth sea.
4	3	04 S.	124	43	30	Cloudy, squally. Smooth sea.
5	2	38 S.	124	33	32	Partly cloudy. Smooth sea.
6	3	04 S.	125	55	88	Partly cloudy. Smooth sea.
7	3	57 S.	126	53	94	Overcast, rainy, squally. Smooth sea. Variable breezes. In Manipa Strait.
8	3	04 S.	127	35	72	Moderate breeze, NW. by W.
9	2	37 S.	127	49	32	squally. Heavy tide rips.
10	1	55 S.	128	22	52	Partly cloudy, squally through Gase Strait. Moderate N. breeze.
11	1	11 S.	128	38	52	Partly cloudy. Smooth sea.
12	0	42 S.	128	55	33	Partly cloudy. Smooth sea. Entered Weda Bay.
13	0	01 S.	128	31	48	Partly cloudy. Smooth sea. In Weda Bay. Light airs from NW.
[illegible]	0	03 S.	129	00	28	Partly cloudy. Long NNE. swell. SW.
15	0	04 N.	129	[illegible]	11	Partly cloudy. Long NNE. swell. Passage.
16	0	29 N.	129	29	54	Partly cloudy. Long swell from NN
17	0	47 N.	130	21	55	Cloudy, squally. Variable breezes.
18	0	49 N.	131	05	44	Partly cloudy. Light breeze, NE. by N.
19	0	23 N.	132	30	89	Partly cloudy. Calm to light airs from NNE. Passing showers.
20	0	55 N.	135	24	176	Partly cloudy.
[illegible]	2	28 N.	137	16	147	Partly cloudy. NNW. squally.
22	3	18 N.	138	29	88	Partly cloudy.
23	4	39 N.	137	24	104	Partly cloudy.
24	7	09 N.	136	14	165	Partly cloudy. Fresh
25	9	07 N.	135	09	135	Partly cloudy. Moderate breeze, NNE.
26	11	09 N.	132	47	186	Partly cloudy. by E.
27	13	11 N.	130	31	131	Partly cloudy.
28	15	23 N.	128	21	183	Partly cloudy.
29	17	08 N.	126	[illegible]	151	NE. breeze.
30	18	33 N.	123	25	193	Strong NE. breeze.
31	18	02 N.	120	14	206	moderate sea.
Feb. 1	15	12 N.	119	35	178	breeze, N. by W.
2	Manila	....	....		101	to smooth sea. Gentle NE. breeze. Arrived at Manila $7^h\ 45^m$ p. m.

Total distance: 8,291 miles. Time of passage: 73.5 days. Average day's run: 112.8 miles.

MANILA TO SUVA, FIJI ISLANDS.

MANILA TO SUVA, FIJI ISLANDS—*concluded.*

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1912	° ′	° ′	*miles*	
May 26	14 12 S.	172 26	182	Partly cloudy. Smooth sea. Fresh breeze from E.
27	16 45 S.	171 29	162	Partly cloudy. Moderate breeze from E.
28	19 27 S.	170 42	170	Partly cloudy, squally. Moderate breeze, ESE.
29	21 20 S.	169 41	128	Clear. SE. trade wind.
30	21 20 S.	170 50	70	Fine clear weather. Light airs from NE.
31	21 35 S.	171 32	44	Overcast, drizzling rain. Light airs from N.
June 1	21 48 S.	172 06	34	Partly cloudy. Calm.
2	21 47 S.	172 28	21	Partly cloudy. Smooth sea. Light airs from S.
3	21 05 S.	174 39	130	Partly cloudy. Smooth sea. Moderate SE. breeze.
4	19 05 S.	176 11	148	Cloudy, squally. Gentle SE. breeze.
5	19 52 S.	176 07	47	Cloudy, squally.
6	19 17 S.	177 42	95	Stood up through Handavu Passage. Fresh SE. breeze.
7	Suva......	....	75	Anchored in Suva Harbor 9 a. m.

Total distance: 8,158 miles. Time of passage: 75.1 days. Average day's run: 108.6 miles.

SUVA, FIJI ISLANDS, TO PAPEETE, TAHITI.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1912	° ′	° ′	*miles*	
June 30	Suva......	....	......	$11^h 55^m$ a. m. taken in tow out of harbor of Suva. $1^h 25^m$ p. m. tugboat cast off.
July 1	18 10 S.	178 45	30	Kept beating off shore until midnight.
2	19 15 S.	177 36	102	$9^h 05^m$ a. m. Cape Washington 7 miles abeam. Fresh SE. breeze.
3	21 18 S.	175 40	168	Cloudy, rainy. Choppy sea. Fresh breeze, ESE.
4	24 07 S.	174 30	181	Overcast, squally. Fresh breeze from E.
5	26 57 S.	175 08	174	Cloudy and squally. Fresh NE. breeze.
6	28 55 S.	177 01	142	Overcast, squally, rain. Light SW. breeze.
7	29 05 S.	178 42	88	Squally. Partly cloudy. Crossed 180th meridian. Fresh breeze from S.
7	29 09 S.	181 25	143	$11^h 30^m$ a. m. Sunday Island sighted ahead. Gentle breeze from S.
8	29 29 S.	182 56	85	Overcast. Light breeze, WNW.
9	29 54 S.	185 22	149	Overcast. Moderate breeze from N.
10	31 20 S.	188 04	174	Cloudy and squally. Gentle breeze, WNW.
11	31 35 S.	189 58	114	Cloudy and squally. Gentle NE. breeze.
12	32 10 S.	192 06	133	Partly cloudy and squally. Rising sea. Fresh NW. breeze.
13	31 58 S.	195 41	183	Cloudy and squally. Heavy sea. Strong breeze from W.
14	31 29 S.	199 00	174	Partly cloudy, squally. Heavy sea. Fresh breeze, W. by S.
15	30 50 S.	202 17	173	Cloudy, passing squalls. Rough sea. Fresh breeze, WSW.
16	30 08 S.	205 52	191	Cloudy and squally. Moderate SW. breeze.
17	30 06 S.	208 29	135	Partly cloudy. Smooth sea. Light breeze from S.
18	30 03 S.	209 36	58	Calm; passing showers.
19	31 49 S.	210 36	118	Heavy rain squalls. Overcast. Fresh NE. breeze.
20	32 26 S.	212 43	114	Squally, with thunder and lightning. Moderate breeze from W.
21	31 34 S.	213 59	84	Partly cloudy. Heavy sea from SE. Fresh breeze, SSE.
22	31 06 S.	215 55	103	Partly cloudy. Moderate breeze, SE. by S.
23	29 51 S.	218 11	139	Partly cloudy. Fresh SE. breeze.
24	28 52 S.	221 13	170	Clear. Gentle breeze, SE. by S.
25	28 34 S.	223 29	70	Cloudy. Smooth sea. Light variable airs.
26	28 08 S.	223 28	57	Partly cloudy. Smooth sea. Light breeze from E.
27	29 27 S.	224 22	92	Squally. Rough sea. Fresh breeze, NE. by N.
28	30 47 S.	225 43	106	Passing squalls. Rising sea. Gentle NE. breeze.
29	31 25 S.	228 10	131	Overcast. Heavy sea from NW. Fresh breeze from NNW.
30	31 31 S.	231 39	179	Rainy. Fresh breeze from WNW.
31	32 05 S.	235 29	198	Cloudy. Strong breeze from WNW.
Aug. 1	31 32 S.	239 04	188	Partly cloudy. Fresh breeze, NW. by W.
2	30 24 S.	242 25	185	Cloudy. Smooth sea. Gentle breeze from WSW.
3	28 28 S.	244 12	149	Clear. Heavy swell from SW. Gentle breeze from SSW.
4	25 40 S.	245 30	182	Partly cloudy. Moderate breeze, E. by N.
5	22 55 S.	245 53	166	Cloudy, squally. Easterly swell. Moderate breeze from E.
6	20 45 S.	245 56	122	Light rain. Moderate breeze, ENE.
7	18 22 S.	245 42	144	Squally. Gentle breeze, E. by N.
8	16 02 S.	245 59	141	Partly cloudy. Gentle breeze, E. by N.
9	12 55 S.	246 12	187	Partly cloudy. Gentle breeze, E. by N.

SUVA, FIJI ISLANDS, TO PAPEETE, TAHITI—*concluded.*

Date	Noon position Lat.		Noon position Long. E. of Gr.		Day's run	Remarks
1912	°	′	°	′	*miles*	
Aug. 10	10	07 S.	246	24	170	Partly cloudy. Smooth sea. Gentle breeze, ENE.
11	7	43 S.	246	07	144	Partly cloudy. Smooth sea. Gentle breeze, E. by N.
12	5	45 S.	246	42	123	Partly cloudy. Moderate sea. Gentle breeze from E.
13	3	34 S.	247	02	133	Partly cloudy. Moderate sea. Light breeze, E. by S.
14	1	01 S.	247	12	154	Partly cloudy. Moderate breeze, E. by N.
15	1	03 N.	247	24	123	Partly cloudy. Smooth sea. Gentle breeze, E. by S.
16	2	08 N.	245	22	137	Clear. Smooth sea. Gentle breeze, SSE.
17	3	04 N.	242	29	182	Partly cloudy. Smooth sea. Moderate breeze, S. by E.
18	4	21 N.	237	38	244	Partly cloudy. Smooth sea. Moderate breeze from SSE.
19	6	01 N.	335	44	200	Cloudy. Smooth sea. Gentle breeze from S.
20	7	01 N.	232	51	182	Partly cloudy. Smooth sea. Moderate breeze from S.
21	6	59 N.	229	53	178	Partly cloudy. Smooth sea. Moderate breeze, S. by E.
22	8	21 N.	227	27	165	Partly cloudy. Smooth sea. Gentle breeze, S. by E.
23	8	27 N.	226	24	63	Overcast, squally. Gentle breeze, S. by E.
24	8	03 N.	228	54	150	Partly cloudy. Gentle breeze, S. by E.
25	7	35 N.	231	45	172	Partly cloudy. Smooth sea. Gentle breeze from S.
26	7	14 N.	233	36	118	Partly cloudy. Smooth sea. Light breeze from S.
27	7	09 N.	234	31	45	Cloudy. Smooth sea. Gentle breeze, S. by E.
28	6	17 N.	233	24	84	Partly cloudy. Smooth sea. Light breeze SE. by S.
29	5	37 N.	232	48	54	Partly cloudy. Smooth sea. Moderate breeze, SE. by S.
30	5	03 N.	230	45	128	Clear. Gentle breeze from SSE.
31	5	15 N.	228	40	124	Partly cloudy. Smooth sea. Gentle breeze from SSE.
Sept. 1	4	35 N.	226	20	146	Partly cloudy. Moderate breeze from SSE.
2	3	00 N.	224	08	162	Cloudy. Moderate SE. breeze
3	0	06 S.	222	34	209	Partly cloudy. Moderate breeze, E. by S.
4	3	15 S.	221	16	207	Partly cloudy. Moderate breeze, from E.
5	5	51 S.	219	50	179	Partly cloudy. Smooth sea. Gentle breeze, ESE.
6	8	11 S.	218	34	168	Partly cloudy. Smooth sea. Gentle breeze, ESE.
7	9	38 S.	216	59	93	Overcast, cloudy and rain. Gentle breeze, E. by S.
8	11	58 S.	217	12	147	Partly cloudy. Moderate breeze, ESE.
9	14	12 S.	215	21	173	Sighted Tioka Island. Moderate ESE. breeze. Partly cloudy.
10	15	21 S.	213	12	146	Partly cloudy. Moderate breeze from ESE.
11	Papeete....		....		205	At daylight sighted Tahiti Island. $1^h 30^m$ p. m., taken in tow into Papeete Harbor. 2 p. m., anchored in Papeete Harbor.

Total distance: 10,525 miles. Time of passage: 74.1 days. Average day's run: 142.0 miles.

PAPEETE TO CORONEL AND TALCAHUANO, CHILE.

Date	Lat.		Long. E. of Gr.		Day's run	Remarks
1912	°	′	°	′	*miles*	
Oct. 15	Papeete....		....		......	$1^h 50^m$ p. m. Taken in tow out of Papeete Harbor.
16	17	38 S.	209	42	55	Partly cloudy. Smooth sea. Gentle breeze, SE. by E.
17	18	53 S.	208	40	95	Overcast, rain. Smooth sea. Gentle breeze from SSE.
18	19	48 S.	206	09	155	Partly cloudy. Moderate breeze, SE. by S.
19	21	47 S.	203	54	174	Partly cloudy. Fresh SE. breeze.
20	24	18 S.	201	55	187	Partly cloudy. Moderate breeze, E. by S.
21	26	16 S.	200	54	130	Overcast. Gentle breeze, E. by S.
22	28	32 S.	201	09	138	Cloudy. Moderate breeze from ENE.
23	31	15 S.	202	33	178	Overcast. Moderate breeze from NNE.
24	33	44 S.	205	44	218	Overcast, squally and rainy. Fresh breeze from NNE.
25	34	59 S.	208	54	174	Overcast, foggy and rainy. Gentle breeze from NNE.
26	35	10 S.	211	13	112	Overcast, passing showers. Light breeze from W. by S.
27	35	54 S.	213	54	139	Partly cloudy. Gentle breeze, N. to W.
28	36	44 S.	216	56	156	Partly cloudy, squally. Gentle NW. breeze.
29	37	14 S.	220	48	192	Partly cloudy, long westerly swell. Moderate breeze, NNW.
30	37	23 S.	223	53	150	Partly cloudy, long swell from west. Light breeze, WSW.
31	37	39 S.	225	41	84	Clear, fine weather. Smooth sea. Light breeze, S. by W.
Nov. 1	37	52 S.	227	15	76	Clear. Light air from W.
2	38	10 S.	228	20	52	Clear. Light air from S.
3	38	46 S.	231	05	135	Partly cloudy, squally. Moderate breeze from W.
4	39	16 S.	234	22	156	Partly cloudy, moderate breeze from W.
5	39	31 S.	236	41	105	Passing showers. Light breeze from SSW.
6	39	39 S.	240	56	205	Heavy sea. Strong breeze, S. by W.
7	39	37 S.	244	07	147	Squally. Heavy sea, SE. swell. Gentle breeze from SSE.
8	39	39 S.	247	33	158	Overcast. Gentle breeze from S. by E. SE. swell.

PAPEETE TO CORONEL AND TALCAHUANO, CHILE—*concluded*.

Total distance: 5,520 miles. Time of passage: 42.4 days. Average day's run: 130.2 miles.

TALCAHUANO, CHILE, TO PORT STANLEY, FALKLAND ISLANDS.

Total distance: 4,033 miles. Time of passage: 30.1 days. Average day's run: 134.1 miles.

PORT STANLEY TO JAMESTOWN, ST. HELENA.

Total distance: 4,606 miles. Time of passage: 40.1 days. Average day's run: 114.9 miles.

JAMESTOWN, ST. HELENA, TO BAHIA, BRAZIL.

Total distance: 1,931 miles. Time of passage: 14.8 days. Average day's run: 130.5 miles.

BAHIA, BRAZIL, TO JAMESTOWN, ST. HELENA.

Total distance: 4,140 miles. Time of passage: 35.6 days. Average day's run: 116.3 miles.

JAMESTOWN, ST. HELENA, TO FALMOUTH, ENGLAND.

1915	° ′	° ′	miles	
July 21	Jamestown	....	....	10ʰ 30ᵐ a. m. left Jamestown. Gentle breeze, NNW.
[illegible]	[illegible] 13 S.	352 [illegible]	136	Partly cloudy. Gentle S. by E.
23	12 03 S.	350 53	170	Partly cloudy, squally. SSE.
24	9 24 S.	348 38	209	Partly cloudy, [illegible]
25	7 33 S.	345 12	228	Partly cloudy.
26	4 45 S.	343 35	193	Partly cloudy, squally.
27	2 44 S.	341 35	171	Partly cloudy. Gentle
28	0 34 S.	340 54	136	Partly cloudy,
29	1 21 N.	340 [illegible]	[illegible]	Partly cloudy.
30	3 04 N.	339 35	[illegible]	Partly cloudy. Light [illegible]
[illegible]	5 07 N.	338 49	[illegible]	Partly cloudy, rain. Light breeze from S.
Aug. 1	[illegible] 05 N.	[illegible] 58	128	Partly cloudy, rain. Light
2	7 38 N.	338 00	33	rain. [illegible] from WSW.
3	[illegible] 00 N.	337 15	149	W. by N. to calm.
4	10 50 N.	337 43	57	variable [illegible]
5	[illegible] 30 N.	336 12	92	Cloudy. Gentle WNW. breeze to calm.
6	10 48 N.	334 [illegible]	[illegible]	Overcast. Gentle NE. breeze.
7	12 08 N.	333 19	120	Partly cloudy, squally. Gentle breeze from ENE.
8	13 50 N.	[illegible] 50	133	Partly cloudy. Gentle [illegible]
9	15 46 N.	329 34	175	Partly cloudy. Moderate NE. breeze.
10	18 36 N.	327 26	209	Partly cloudy. Moderate breeze from ENE.
[illegible]	20 59 N.	325 16	187	Partly cloudy. Moderate breeze from NE by E. Squally.

JAMESTOWN, ST. HELENA, TO FALMOUTH, ENGLAND—concluded.

Total distance: 6,051 miles. Time of passage: 53.1 days. Average day's run: 114.0 miles.

FALMOUTH TO GREENPORT, LONG ISLAND.

J. P. AULT: ABSTRACT OF LOG, CRUISE III, 1914.

BROOKLYN, NEW YORK, TO HAMMERFEST, NORWAY.

Date	Noon position Lat.	Noon position Long. E. of Gr.	Day's run	Remarks
1914	° ′	° ′	*miles*	
June 8	Brooklyn..	....	....	1h 25m p. m. left Erie Basin in tow. 5h 05m p. m. anchored off Matinicock Point. Head wind and tide.
9	Matinicock	Point....	....	4h 35m p. m. left anchorage. Moderate breeze from ENE.
10	41 03 N.	288 36	102	Discharged pilot at 6h 40m a. m. At 6h 35m p. m. seaman Bosanquet fell overboard and drowned. Fresh SW. breeze.
11	40 34 N.	292 12	168	Light breeze from W. Clear.
12	40 21 N.	295 22	190	Moderate SW. breeze. Overcast.
13	40 03 N.	300 11	220	Fresh SW. breeze. Squally.
14	40 11 N.	305 07	226	Variable winds. Overcast, rain.
15	39 22 N.	307 05	104	Variable winds. Overcast, rain.
16	40 45 N.	310 32	180	Fresh breeze from SW by S. Cloudy.
17	42 44 N.	313 10	167	Moderate SW. breeze. Cloudy, fog.
18	45 13 N.	316 36	210	Fresh NW. breeze. Cloudy.
19	46 07 N.	321 30	211	Moderate NW. breeze. Clear.
20	46 28 N.	324 21	120	Moderate SW. breeze. Overcast, rain.
21	48 21 N.	328 45	210	Fresh NW. breeze. Cloudy, rain.
22	50 44 N.	331 36	181	Moderate breeze from W. Fog, rain.
23	52 50 N.	334 53	175	Moderate breeze from W. Cloudy.
24	54 58 N.	338 16	125	Moderate NW. breeze. Cloudy.
25	57 10 N.	342 11	186	Fresh breeze from W. Cloudy.
26	59 48 N.	346 56	217	Moderate breeze from W. Overcast, rain.
27	62 16 N.	352 20	217	Fresh breeze from WNW. Squally.
28	64 28 N.	359 31	233	Fresh NW. breeze. Overcast.
29	66 56 N.	5 31	209	Fresh NW. breeze. Overcast, rain, squally.
30	67 45 N.	8 03	76	Variable winds. Overcast, cloudy.
July 1	70 18 N.	13 00	186	Fresh breeze from SSW. Squally, rain.
2	71 01 N.	18 46	122	Strong SW. breeze to gale. Squally.
3	Hammerfest	....	117	Anchored at Hammerfest 1 a. m.

Total distance: 4,152 miles. Time of passage: 24.5 days. Average day's run: 169.5 miles.

HAMMERFEST, NORWAY, TO REYKJAVIK, ICELAND.

Date	Lat.	Long. E. of Gr.	Day's run	Remarks
1914	° ′	° ′	*miles*	
July 25	Hammerfest	....	....	At 3h 12m p. m. left Hammerfest under own power. Swung ship in outer bay.
26	72 15 N.	21 20	100	Moderate breeze from NE. by N. Overcast.
27	73 29 N.	16 02	119	Moderate NE. breeze to calm. Overcast.
28	73 28 N.	16 01	1	Calm. Overcast.
29	73 52 N.	16 03	24	Light airs from NNW. Overcast.
30	74 30 N.	16 55	41	Light airs. Overcast.
31	75 18 N.	16 10	49	Light winds. Cloudy, overcast. Sighted growlers.
Aug. 1	76 40 N.	13 49	89	Ice pack sighted, 1 a. m. Gentle SW. breeze. Overcast.
2	78 24 N.	8 47	123	Light to strong wind from SSW. Misty, overcast.
3	79 47 N.	8 54	83	Strong SW. winds. Rain, fog, mist.
4	79 19 N.	8 49	28	Strong winds from S. Cloudy. Engine running.
5	79 05 N.	10 19	22	Strong winds from S. Overcast, fog. Engine running.
6	78 29 N.	9 30	37	Moderate variable breezes. Fog.
7	77 13 N.	4 48	97	Moderate variable breezes to calm. Overcast. Swung ship.
8	76 29 N.	3 13	48	Moderate breeze from NNE. Cloudy, overcast.
9	74 48 N.	0 10	111	Moderate variable breezes. Overcast, rain, fog.
10	72 03 N.	356 20	176	Moderate breeze from NE. by E. Rain, fog, mist.
11	71 11 N.	355 12	56	Light to moderate NE. breeze. Fog, rain.
12	69 05 N.	353 15	132	Variable breezes. Overcast.
13	66 55 N.	353 31	130	Variable breezes. Overcast, mist.
14	66 46 N.	353 19	10	Moderate breeze from WSW. Fog.
15	65 28 N.	355 20	92	Moderate breeze from WSW. Overcast, fog.
16	65 51 N.	353 44	57	Moderate breeze from W. Overcast, fog.
17	64 47 N.	353 44	64	Moderate, variable breezes. Overcast, fog.
18	65 04 N.	351 22	62	Variable breezes. Fog, overcast.
19	64 11 N.	351 04	54	Calm to light variable breezes. Overcast, cloudy.
20	63 57 N.	348 56	58	Light SE. breeze. Cloudy.
21	63 23 N.	345 16	103	Light variable breezes. Cloudy, overcast.
22	62 59 N.	341 14	112	Strong wind from ESE. Cloudy, overcast, squalls.
23	63 45 N.	337 11	118	Variable breezes. Cloudy. Tacking off coast of Iceland.
24	Reykjavik.	....	29	Light breeze from ENE. Overcast, cloudy. At 2h 40m p. m. anchored.

Total distance: 2,225 miles. Time of passage: 30 days. Average day's run: 74.2 miles.

1

2

3

4

5

PLATE 19

Typical Views of Shore Stations.

1. Freitas Beach, near Rio de Janeiro, 1910.
2. Jaburu, near Bahia, 1913.
4. Sweetwater, Colon, 1915.
5. Christchurch Magnetic Observatory, 1915.

REYKJAVIK, ICELAND, TO GREENPORT, NEW YORK.

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1914	° ′	° ′	*miles*	
Sept. 13	Reykjavik	....	....	At $1^h 45^m$ p. m. left Reykjavik. Squally.
14	62 42 N.	333 10	164	Strong wind from N. by W. Rough sea. Squalls.
15	60 33 N.	328 58	175	Fresh NE. breeze. Cloudy, showers.
16	58 20 N.	323 21	216	Fresh NE. breeze. Moderating sea, cloudy.
17	58 11 N.	319 30	122	Light to moderate breeze from ENE. Cloudy.
18	58 03 N.	315 28	128	Moderate breeze from ESE. Cloudy.
19	57 56 N.	310 22	163	Moderate E. breeze. Cloudy, misty.
20	58 34 N.	306 06	140	Moderate breeze from NNE. Cloudy, rain.
21	55 50 N.	306 19	177	Moderate to light variable breezes. Cloudy.
22	54 37 N.	307 31	83	Light variable breezes. Cloudy.
23	53 50 N.	309 02	71	Fresh to light westerly breezes. Cloudy, fog, rain.
24	52 49 N.	309 52	68	Light NE. breeze. Cloudy, overcast.
25	51 39 N.	310 24	73	Light to moderate SW. breeze. Fog, rain.
26	51 17 N.	312 13	72	Light to moderate variable breezes. Fog, mist.
27	49 51 N.	311 38	89	Moderate westerly breeze to gale. Misty, clear.
28	48 56 N.	312 36	68	Gale to light northerly breezes. Clear.
29	47 04 N.	311 22	123	Moderate breeze from SSE. Overcast, rain, clear.
30	47 00 N.	309 12	89	Fresh variable winds. Cloudy, rain.
Oct. 1	46 18 N.	309 05	42	Variable winds. Squalls, cloudy.
2	45 09 N.	307 18	104	Fresh variable winds. Overcast, rain.
3	43 46 N.	303 07	197	Moderate NNW. breeze. Clear, cloudy.
4	43 10 N.	302 47	68	Moderate NNE. breeze. Clear.
5	42 52 N.	299 47	89	Light to moderate SW. breeze. Clear.
6	42 36 N.	297 24	107	Moderate to strong breeze from NNE. Overcast, clear.
7	41 35 N.	293 48	171	Moderate to light variable breezes. Cloudy, clear.
8	41 30 N.	293 16	25	Gentle breeze to light air from WSW. Clear.
9	40 58 N.	291 52	71	Light variable air. Fog.
10	40 49 N.	290 28	65	Light to moderate breeze from S. Fog followed by clear weather.
11	41 08 N.	287 57	116	$8^h 15^m$ a. m. anchored off Gardiners Island. Head wind.
12[1]	Greenport	....	16	$8^h 30^m$ a. m. left anchorage and proceeded under engine-power to Greenport. $1^h 12^m$ p. m. anchored in Greenport Harbor. Head wind.

Total distance: 3,092 miles. Time of passage: 29 days. Average day's run: 106.6 miles.

[1]After swinging ship and making final observations, the *Carnegie* left Gardiners Bay under her own power at $11^h 15^m$ a.m. October 21, arriving at Brooklyn 4 p.m. of same day.

Summary of Passages for Cruise III of the Carnegie.

TABLE 69.

Passage	Length of passage	Time of passage	Average day's run
	miles	*days*	*miles*
Brooklyn to Hammerfest......	4,152	24.5	170
Hammerfest to Reykjavik.....	2,225	30.0	74
Reykjavik to Greenport.......	3,092	29.0	107
Greenport to Brooklyn........	91	0.2	...

Length of Cruise III: 9,560 miles. Time at sea: 83.7 days. Average day's run: 114 miles.

J. P. AULT: ABSTRACT OF LOG, CRUISE IV, 1915-1916.

BROOKLYN TO COLON, PANAMA.

Total distance: 2,487 miles. Time of passage: 16.4 days. Average day's run: 151.6 miles.

[1]The *Carnegie* left Colon Harbor in tow April 7, at $8^h\,25^m$ a.m., to pass through the Panama Canal, and arrived at Pedro Miguel at 4 p.m. Leaving Pedro Miguel the next morning at $7^h\,30^m$, the vessel arrived at Balboa, April 8, at $10^h\,45^m$ a.m.

BALBOA, CANAL ZONE, TO HONOLULU.

1915	°	′	°	′	miles	
Apr. 12	Balboa....		....		....	At 10 a. m. left Balboa.
13	6	30 N.	279	56	151	Clear.
14	5	32 N.	279	44	59	Light
15	3	59 N.	279	33	[redacted]	Light Swung ship.
16	2	36 N.	278	09	119	Light breeze. Partly cloudy.
17	2	09 N.	276	18	114	Light breeze. Partly cloudy.
18	2	26 N.	273	44	155	[illegible]
19	2	10 N.	271	54	111	
20	2	10 N.	269	33	141	Gentle breeze.
21	2	58 N.	267	14	147	Gentle breeze.
22	3	42 N.	264	35	165	Gentle breeze. Cloudy. Showers.
23	4	55 N.	263	53	85	Light variable winds. Cloudy, squally.
24	4	28 N.	263	55	27	Light winds. Partly cloudy.
25	3	49 N.	264	40	59	Light variable winds. Partly cloudy.
26	4	15 N.	[redacted]		[redacted]	Light breeze. Cloudy, squally.
27	4	57 N.	262	11	[redacted]	Gentle to light breeze. Passing showers.
[redacted]	6	27 N.	261	17	105	Gentle
29	8	12 N.	260	39	112	Gentle y cloudy.
30	8	29 N.	259	47	54	
May 1	8	39 N.	257	56	110	
2	9	51 N.	255	33	167	
3	10	19 N.	253	36	109	
4	10	25 N.	250	14	199	Moderate breeze. loudy.
5	11	08 N.	247	40	156	Moderate breeze. loudy.
6	11	53 N.	244	53	170	Moderate breeze.
7	12	46 N.	241	55	182	[illegible]
8	13	38 N.	239	17	163	showers.
9	14	42 N.	235	58	208	
10	15	50 N.	232	46	196	Partly cloudy.
11	16	49 N.	[redacted]		164	Moderate breeze. Showers.
12	17	28 N.	227	10	173	Moderate breeze. Cloudy, showers.
[redacted]	18	10 N.	224	02	184	Fresh breeze. Partly cloudy.

BALBOA, CANAL ZONE, TO HONOLULU—*concluded.*

Total distance: 5,303 miles. Time of passage: 39 days. Average day's run: 136.0 miles.

HONOLULU TO DUTCH HARBOR, ALASKA.

Total distance: 2,326 miles. Time of passage: 16.9 days. Average day's run: 137.6 miles.

DUTCH HARBOR TO PORT LYTTELTON, NEW ZEALAND.

DUTCH HARBOR TO PORT LYTTELTON, NEW ZEALAND—*concluded.*

Date	Noon position				Day's run	Remarks
	Lat.		Long. E. of Gr.			
1915	°	′	°	′	*miles*	
Sept. 1	30	06 N.	171	11	107	Partly cloudy. Gentle breeze. Smooth sea.
2	29	08 N.	170	42	63	Partly cloudy. Light airs. Smooth sea.
3	28	31 N.	170	10	[illegible]	Partly cloudy. Gentle breeze. Smooth sea.
4	26	10 N.	169	01	145	Cloudy. Fresh breeze.
5	22	[illegible] N.	167	[illegible]	234	Squally.
6	20	22 N.	167	05	134	Squally, r gale. Heavy swell.
7	21	28 N.	169	20	[illegible]	Squally, rain. gentle breeze. Heavy swell.
8	21	19 N.	169	30	[illegible]	Cloudy.
9	21	01 N.	168	35	55	Cloudy. Becalmed. Moderate swell.
10	20	[illegible] N.	168	[illegible]	30	Cloudy. Light airs. Long swell.
11	19	56 N.	167	24	64	Partly cloudy. Gentle breeze.
12	[illegible]	52 N	[illegible]	19	89	Clear. Gentle ake Island.
13	17	00 N.	165	29	122	Partly cloudy.
14	15	18 N.	165	22	103	Overcast, rain.
15	14	15 N.	164	58	67	Cloudy, squally. Light airs.
16	13	52 N.	166	06	70	Cloudy. Fresh wind to calm.
17	13	35 N.	166	[illegible]	[illegible]	Partly cloudy. Calm to moderate breeze.
18	12	10 N.	164	[illegible]	124	Partly cloudy. Calm to moderate breeze.
19	11	17 N.	164	21	59	Clear. Light
20	10	12 N.	164	08	[illegible]	Partly cloudy. Smooth sea.
21	[illegible]	55 N.	163	42	81	Clear. Moderate breeze.
22	8	03 N.	163	[illegible]	53	Squally, overcast. Moderate breeze.
23	7	01 N.	164	15	69	Partly cloudy. Gentle breeze. Smooth sea.
24	5	22 N.	164	48	[illegible]	Partly . Smooth sea.
25	4	18 N.	164	07	[illegible]	Clear.
26	3	58 N.	164	01	21	Light
27	3	40 N.	163	58	[illegible]	Cloudy. Calm
28	3	23 N.	163	10	51	Partly cloudy.
29	[illegible]	07 N.	162	[illegible]	59	Partly cloudy. Light air and smooth sea.
30	2	23 N.	[illegible]	46	52	Light air. Smooth sea. Thunder.
Oct. 1	1	57 N.	160	44	[illegible]	Partly cloudy. Moderate breeze. Smooth sea.
2	0	25 N.	160	00	[illegible]	Clear. Moderate breeze.
3	2	[illegible] S.	160	[illegible]	151	Partly cloudy. Fresh breeze. SE. swell.
4	4	12 S.	161	[illegible]	[illegible]	Partly cloudy. Moderate breeze. SE. swell.
5	5	07 S.	[illegible]	16	81	Squally, rain. SE. swell.
6	5	[illegible] S.	[illegible]	33	86	Cloudy. Light sea.
7	6	21 S.	164	04	45	Squally, rain. Smooth sea.
8	7	41 S.	163	22	90	Partly cloudy. Gentle breeze. Sighted Stewart I. from upper topsail yard.
9	9	28 S.	162	53	111	Partly cloudy. Gentle breeze. Sighted Ulawa Island and a waterspout.
10	10	23 S.	162	51	55	Squally. Thunder and lightning in the morning. San Cristoval and Owa Riki Islands sighted.
11	11	43 S.	162	13	89	Partly cloudy. Fresh breeze.
12	12	52 S.	160	53	104	Partly cloudy. Fresh breeze. Breakers on Indispensable Reef sighted.
13	13	58 S.	159	[illegible]	86	Partly cloudy. Moderate breeze and calm.
14	[illegible]	22 S.	158	32	166	Partly cloudy. Fresh breeze.
15	19	29 S.	157	45	192	Partly cloudy. Fresh breeze.
16	21	42 S.	157	27	134	Clear. Smooth sea.
17	22	20 S.	157	[illegible]	[illegible]	Partly breeze.
18	23	35 S.	157	[illegible]	75	Clear. breeze.
19	24	23 S.	[illegible]	[illegible]	[illegible]	breeze.
20	26	09 S.	[illegible]	24	127	Partly cloudy. Moderate breeze.
21	28	04 S.	[illegible]	37	123	Clear. Gentle breeze. Smooth sea.
22	30	10 S.	155	36	[illegible]	Partly cloudy. Fresh breeze.
23	33	08 S.	157	26	203	Cloudy. Strong breeze. Rough sea.
24	35	36 S.	158	26	155	Cloudy, variable winds. Choppy sea.
25	36	21 S.	159	[illegible]	[illegible]	Cloudy. Variable winds and calm.
26	37	12 S.	161	26	[illegible]	Partly cloudy. Moderate breeze.
27	38	25 S.	162	00	78	Partly cloudy. Squally. Moderate breeze.
28	39	16 S.	[illegible]	08	51	Partly cloudy. Light air to moderate breeze.
29	41	50 S.	162	[illegible]	157	Overcast, rain. Fresh
30	44	51 S.	164	18	193	Cloudy.
31	46	35 S.	[illegible]	58	185	Overcast. In Foveaux Strait all day.
Nov. 1	46	16 S.	170	22	[illegible]	Overcast, gentle breeze, smooth sea.
2	44	44 S.	172	[illegible]	[illegible]	Partly cloudy. Gentle breeze.
3	Lyttelton			. . .	68	At 10^h 30^m a. m. alongside of dock, Lyttelton Harbor.

Total distance: 8,865 miles. Time of passage: 89 days. Average day's run: 99.6 miles.

Port Lyttelton to South Georgia and to Port Lyttelton.

PORT LYTTELTON TO SOUTH GEORGIA AND TO PORT LYTTELTON—*concluded.*

Total distance: 17,084 miles. Time of passage: 118 days. Average day's run: 144.8 miles.

PORT LYTTELTON TO PAGO PAGO, SAMOA.

PORT LYTTELTON TO PAGO PAGO, SAMOA—*concluded.*

Total distance: 2,596 miles. Time of passage: 22 days. Average day's run: 118.0 miles.

PAGO PAGO TO PORT APRA, GUAM.

Total distance: 3,987 miles. Time of passage: 27.2 days. Average day's run: 146.6 miles.

PORT APRA, GUAM, TO SAN FRANCISCO.

PORT APRA, GUAM, TO SAN FRANCISCO—*concluded.*

Date	Noon position		Day's run	Remarks
	Lat.	Long. E. of Gr.		
1916	° ′	° ′	*miles*	
Aug. 14	27 03 N.	144 25	208	Fresh breeze. SSW. swell. Cloudy.
15	30 08 N.	143 59	185	Strong to light breeze. Overcast.
16	30 18 N.	144 20	20	Calm to gentle breeze. Cloudy.
17	31 58 N.	143 40	106	Moderate breeze. Overcast, drizzling.
18	34 14 N.	146 09	185	Strong breeze. High sea. Rain.
19	36 26 N.	150 30	251	Strong breeze. Squally, rain.
20	38 38 N.	154 05	215	Moderate breeze. Overcast, drizzling.
21	40 29 N.	156 39	162	Gentle breeze. Westerly swell. Overcast.
22	42 51 N.	158 26	134	Moderate breeze. Overcast.
23	44 57 N.	159 20	132	Gentle breeze. Smooth sea. Partly cloudy.
24	46 24 N.	160 26	99	Light air. Smooth sea. Overcast.
25	46 56 N.	163 06	113	Light breeze. Smooth sea. Cloudy.
26	47 08 N.	165 22	93	Swinging ship under engine power for H and I.
27	47 16 N.	167 49	100	Swinging ship for D, 5 headings 1 helm.
28	47 25 N.	169 08	54	Light breeze. Partly cloudy. Under engine power.
29	47 39 N.	171 22	92	Gentle breeze. Overcast, rain.
30	48 20 N.	175 20	164	Fresh breeze. Overcast. Crossed 180th meridian.
30	48 55 N.	180 04	191	Gentle breeze. SW. swell. Misty and foggy.
31	49 30 N.	182 20	95	Light breeze. Smooth sea. Overcast.
Sept. 1	49 53 N.	184 16	78	Light breeze. Smooth sea. Overcast.
2	50 59 N.	187 28	139	Moderate breeze. Overcast, rain.
3	51 31 N.	192 02	174	Fresh breeze. High sea. Overcast, misty.
4	51 57 N.	196 07	154	Light breeze. WNW. swell. Overcast.
5	52 38 N.	199 25	128	Moderate breeze. Overcast.
6	53 16 N.	204 16	180	Moderate breeze. Overcast, drizzling.
7	52 55 N.	208 32	155	Gentle breeze. Smooth sea. Misty, drizzling.
8	51 48 N.	212 24	157	Strong breeze. High sea. Misty, foggy.
9	49 33 N.	215 51	187	Moderate breeze. Foggy.
10	47 14 N.	218 44	179	Moderate breeze. Foggy.
11	45 30 N.	220 36	130	Moderate breeze. Foggy, misty.
12	43 21 N.	221 43	134	Moderate breeze. Overcast.
13	41 18 N.	221 44	123	Moderate breeze. Overcast.
14	40 56 N.	221 46	23	Light air and calm. Overcast.
15	40 47 N.	221 58	12	Calm to gentle breeze. Overcast.
16	40 40 N.	224 54	134	Moderate breeze. Overcast.
17	40 08 N.	228 50	182	Moderate breeze. Overcast.
18	39 28 N.	230 44	97	Fresh breeze. Overcast.
19	38 37 N.	234 09	165	Moderate breeze. Overcast.
20	38 17 N.	235 31	67	Light air. Smooth sea. Foggy, misty.
21	San Francisco........		109	Anchored at Quarantine, San Francisco, at $11^h\ 30^m$ a. m.

Total distance: 5,937 miles. Time of passage: 45.9 days. Average day's run: 129.3 miles.

Summary of Passages for Cruise IV of the Carnegie as far as San Francisco, September 21, 1916.

TABLE 70.

Passage	Length of passage	Time of passage	Average day's run
	miles	*days*	*miles*
Brooklyn to Colon................	2,487	16.4	152
Colon to Balboa.................	42	0.5	....
Balboa to Honolulu..............	5,303	39.0	136
Honolulu to Dutch Harbor........	2,326	16.9	138
Dutch Harbor to Port Lyttelton..	8,865	89.0	100
Port Lyttelton to Port Lyttelton...	17,084	118.0	145
Port Lyttelton to Pago Pago......	2,595	22.0	118
Pago Pago to Guam............	3,987	27.2	147
Guam to San Francisco..........	5,937	45.9	129

Length of Cruise IV as far as San Francisco: 48,626 miles. Time at sea: 374.9 days. Average day's run: 130 miles.

Final Summary for Cruises of the Carnegie, 1909–1916 (September 21).

TABLE 71.

Cruise	Length of passage	Time of passage	Average day's run
	miles	*days*	*miles*
I, 1909–10.....	9,600	96	100
II, 1910–13.....	92,829	798	116
III, 1914	9,560	84	114
IV, 1915–16.....	48,626	375	130

Total length of cruises 1909 to September 21, 1916: 160,615 miles.
Total time at sea: 1,353 days. Average day's run: 119 miles.

The total number of days the *Carnegie* was in commission from September 1, 1909, to September 21, 1916, counting out the periods February 18 to June 19, 1910, December 20, 1913, to June 7, 1914, and October 22, 1914, to March 5, 1915, when the vessel was at Brooklyn, is 2,151 days. Since 1,353 days were spent at sea, the remaining days, 798, are to be ascribed to the time consumed at ports in shore observations and comparisons of instruments, computations, repairs, and outfitting.

AUXILIARY OBSERVATIONS ON THE CARNEGIE.

In addition to observations in terrestrial magnetism, the scientific work aboard the *Carnegie*, as far as time and conditions permitted, included atmospheric electricity. An account of this work will be found in the special report on results in atmospheric electricity (see pp. 361–422).

Furthermore, observations were made regularly to determine the amount of atmospheric refraction by measuring the dip of the horizon with the dip-of-horizon measurer (Kimmtiefenmesser), by Carl Zeiss of Jena. A future special report will deal with this subject.

Meteorological observations were made to the following extent: Every 4 hours at sea, the wind direction and force were noted. At the same time, temperatures of the sea-surface and the air were recorded and readings of the wet-bulb thermometer were taken. In addition to these usual meteorological notes, special observations were made at Greenwich mean noon according to the forms prepared by the United States Weather Bureau for observations at sea. The ship's aneroids were controlled, from time to time, by special boiling-point observations at sea and by port comparisons with standard barometers, whenever opportunity afforded. Beginning at Dutch Harbor, Alaska, special attention was also paid to occurrences of thunder at sea (see pp. 325 and 326).

The Greenwich mean noon observations, together with notes on more or less closely allied phenomena (storms, polar lights, unusual meteorological events, etc.), were regularly transmitted to the United States Weather Bureau for discussion along with the ocean data received by that Bureau from other sources.

SPECIAL INVESTIGATIONS.

Numerous investigations have been made with reference to various matters which have come up, from time to time, in connection with the many interesting problems presented in the course of the scientific work on the *Galilee* and the *Carnegie*. Some of these have already been fully treated in various sections of this volume. Others, for lack of time and space, have only been referred to. Still others could receive no mention at all. It is hoped that there will be opportunity to give in detail some of the additional investigations in future volumes. Our first endeavor has been to give the main results of the ocean work to date.

STATUS OF THE GENERAL MAGNETIC SURVEY OF OCEAN AREAS.

On Plate 20, the cruises of the *Galilee*, 1905–1908, and the *Carnegie*, 1909–1916 (September), are shown, the former by black lines and the latter by red ones. The red dots indicate the land magnetic stations (about 3,500) established by the Department of Terrestrial Magnetism from 1905 to October 1916; they are distributed over 115 different countries and island groups, being located especially in regions where no magnetic results, or but an insufficient number, had been obtained previously. The red dots in Hudson Strait and Hudson Bay represent the points at which magnetic observations were obtained by the Department in 1914 on the chartered gasoline schooner, the *George B. Cluett*.

The directions in which the various passages were made are indicated by arrow-heads. The Arabic numbers, 1, 2, and 3, designate, respectively, the three cruises of the *Galilee* (August 1905 to May 1908); the Roman numbers, I, II, III, and IV, refer to the four cruises of the *Carnegie* carried out from August 1909 to September 1916. Plate 20 thus shows the status of the general magnetic survey of ocean areas as represented by the cruises of the two vessels, the *Galilee* and the *Carnegie*, from August 1905 to September 1916.

TABLE 72.—*Summary of the Ocean Magnetic Work of the Galilee and the Carnegie, 1905–1916 (September).*

Vessel and Cruise	Number		No. of obs'd values			Average time interval			Average distance apart		
	Days	Miles	Decl'n	Incl'n	Hor. Int.	Decl'n	Incl'n	Hor. Int.	Decl'n	Incl'n	Hor. Int.
						days	*days*	*days*	*miles*	*miles*	*miles*
Galilee, Cruise I, 1905	92	10,571	74	58	59	1.2	1.6	1.6	143	182	179
Galilee, Cruise II, 1906	168	16,286	95	88	91	1.8	1.9	1.8	171	185	179
Galilee, Cruise III, 1906–08	334	36,977	156	169	171	2.1	2.0	2.0	237	219	216
Totals for *Galilee*	594	63,834	325	315	321	1.8	1.9	1.9	196	203	199
Carnegie, Cruise I, 1909–10	96	9,600	98	68	69	1.0	1.4	1.4	98	141	139
Carnegie, Cruise II, 1910–13	798	92,829	858	648	643	0.9	1.2	1.2	108	143	144
Carnegie, Cruise III, 1914	84	9,560	108	81	80	0.8	1.0	1.0	89	118	119
Carnegie, Cruise IV, 1915–16	375	48,626	665	369	368	0.6	1.0	1.0	73	132	132
Totals for *Carnegie*	1,353	160,615	1,729	1,166	1,160	0.8	1.2	1.2	93	138	138
Totals for *Galilee* and *Carnegie*	1,947	224,449	2,054	1,481	1,481	0.9	1.3	1.3	109	152	152

Table 72 shows for each cruise of the *Galilee* and of the *Carnegie* the number of days at sea,[1] the length of the cruise in nautical miles, and the number of observed values of the magnetic declination, inclination, and intensity of the Earth's magnetic field. The subsequent columns give the average time-intervals, as well as the average distances apart, between the observations. The entries in the bottom row of the table summarize the work of the two vessels from August 1905 to September 1916. It will be seen that the aggregate length of all the cruises of the *Galilee* and *Carnegie* through September 1916, is 224,449 nautical miles. The length of the return passage (see broken red lines on Plates 23 and 24) from San Francisco to Brooklyn, November 1916 to October 1917, is expected to be about 30,600 miles. Accordingly, when the present cruise (No. IV) of the *Carnegie* has been completed, namely, by the end of 1917, the aggregate length of the cruises of the two vessels will be about 255,000 nautical miles.

It is seen from Table 72 that the average time-intervals and average distances apart for the *Galilee* work have been decreased by about 45 per cent in the *Carnegie* work. The increased efficiency, or productiveness, has resulted from the fact that the *Carnegie* is a non-magnetic vessel and because of the steady improvement in the instrumental appliances and observational methods.

[1]In the case of the *Galilee* work, to the number of days at sea were added the days spent in the harbor-swings.

REPORTS ON SPECIAL RESEARCHES

RESULTS OF ATMOSPHERIC-ELECTRIC OBSERVATIONS MADE ABOARD THE GALILEE (1907–1908) AND THE CARNEGIE (1909–1916).

By L. A. Bauer and W. F. G. Swann.

[Based on Observations and Reports by J. P. Ault, P. H. Dike, C. W. Hewlett, H. F. Johnston, B. Jones, E. Kidson, I. A. Luke, S. J. Mauchly, W. J. Peters, and W. F. G. Swann.]

INTRODUCTION.

From the beginning of the ocean work of the Department of Terrestrial Magnetism, it has been its aim to include in the program of scientific work whatever additional observational researches could be carried on advantageously and profitably without conflicting with the prime object assigned to the Department—the general magnetic survey of the globe. Manifestly it is necessary to restrict our efforts now-a-days to a few specific problems, if the results achieved are to have definite, scientific value. It appears that expeditions designed to undertake research in many and miscellaneous subjects, the interests of which not infrequently clash, are not likely to meet the rigid and exacting requirements of science to-day, though, in their time, such general expeditions had a distinct and well-recognized value.

The history of modern investigation shows that in most sciences we have not yet reached beyond the observational and experimental stages. It appears that hypotheses and theories should serve chiefly as stepping-stones to still more intensive and unceasing experimentation and observation. We must be fully content if they serve both to stimulate further interest and to cause us to conduct our work with increasing intelligence and discernment. But this implies that we quickly determine in what direction our observations and experiments are leading us—in other words, that we so arrange our program of work as to admit of prompt reduction and discussion of results. In brief, we must not permit observations and experimental results to accumulate to such an extent as to make well-nigh impossible their publication within a reasonable period.

The experiences just alluded to seem to require that a piece of research should be undertaken for a given period of years systematically and unceasingly, not spasmodically, and that during this period the work should be so arranged as to permit obtaining the results striven for, expeditiously; moreover, that it should be possible to make opportunely and with promptness any necessary improvement in the work. Now these requirements set a definite limit to work of any kind which may be undertaken, especially such as is of world-wide extent. No one vessel can meet the precise needs of many sciences, nor can any one scientific party be large enough to grapple advantageously with more than a comparatively few sets of problems. Indeed, as additional experience is gained in the conduct of world problems which must be kept going continuously for a period of years, the more and more does this conclusion appear to be emphasized: Keep the problems as few as possible, and have the scientific party no larger than is necessary to solve such

problems successfully and harmoniously. No commander of vessel and no one set of observers can be kept continuously engaged on the strenuous program which even but three or four great problems entail. New men must be continually trained to assume the responsibilities and tasks of their predecessors.

The preceding paragraphs must suffice to show why it is necessary to limit our ocean investigational work to subjects which fall naturally within the province of the work of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and why also we are prohibited, for the present at least, from undertaking some other important lines of inquiry.

It is hoped that these prefatory remarks will serve to introduce the reports on special ocean researches, contained in this volume and subsequent ones, as also to give a slight indication of the difficulties of administration and direction.

The problem which naturally suggests itself as closely related to that of terrestrial magnetism is that of terrestrial electricity. By the latter term is meant the science pertaining to the electrical phenomena exhibited by the Earth and the atmosphere. The subjects of investigation embrace: (*a*) the electric currents circulating within the Earth's crust, (*b*) the Earth's electric charge, and (*c*) the conducting properties of the atmosphere. Subject (*a*) at present is one of combined laboratory and observatory investigation. Subjects (*b*) and (*c*) together form the science termed "atmospheric electricity." It is only with regard to field observations and results in the latter that the present report concerns itself.

Professors J. Elster and H. Geitel, in their letter to the Carnegie Institution of Washington, dated Wolfenbüttel, Germany, January 26, 1902, made the following recommendations:

> With the earnest hope that this proposal may meet with your approval, we beg leave to suggest that it would be in full harmony with the proposed plan to combine with the organization of international magnetic work also the inauguration of observations pertaining to the electric condition of the Earth and of the atmosphere, even though this at present may be possible only to a limited extent.
>
> As the principal electric problems, we might name the determination of the strength of the Earth's electric field and of the electric conductivity of the atmosphere (the so-called dissipation of electricity), and the investigation of earth-currents and the aurora.
>
> Since these matters have been investigated only within comparatively recent times, the methods of observation and of reduction and the theoretical utilization of the results are as yet very imperfect. Nevertheless, there is reason to hope that, even with the present means, relationships between the electric phenomena of the atmosphere and the Earth's magnetic phenomena can be disclosed.
>
> At comparatively small cost for instrumental means and without adding very much to the work of the observer, it would be possible, in our opinion, to institute systematic measurements of the electric intensity of the Earth's field and of the conductivity of the atmosphere at a few magnetic observatories as widely distributed as possible. A few years' results at these places would then show whether it would be desirable to increase the number of stations or expand the work in other directions.

Since their proposals were made, these eminent pioneer investigators in atmospheric electricity have unceasingly shown their interest and have rendered

OBSERVATIONS ON CRUISE III OF THE GALILEE, 1907-1908.

(W. J. PETERS IN COMMAND.)

The observations included measurements of the potential-gradient, conductivity, and the radioactive deposit on a charged wire. They were made on the cruise of the *Galilee* from Sitka (Alaska) to Honolulu (Hawaiian Islands), Marshall Islands, Lyttelton (New Zealand), Callao (Peru), and San Francisco, during the period August 12, 1907, to May 15, 1908. The observer was P. H. Dike, who had been sent to Europe in 1906 by the Department of Terrestrial Magnetism to receive special training, for the proposed atmospheric-electric work, at Berlin and Potsdam, at Wolfenbüttel (under Professors Elster and Geitel) and at the University of Cambridge. The following extracts are taken from his report.[1]

The determination of the potential-gradient, after careful consideration of the conditions on board a sailing vessel, seemed quite impracticable, and no serious attempt was made to secure observations. The rolling of the ship, the flapping of the sails, and the varying positions of the yards and boom under various sailing conditions all contributed to make the problem of reducing observations of potential-gradient to a uniform basis too complicated to be undertaken in the initial work. On board a steamer the conditions would be less variable and it might be possible to reduce readings to values for undisturbed sea by means of simultaneous observations in port with the vessel at anchor and the second collector and electroscope mounted on a raft at some distance from the vessel.

It was possible only once to secure potential observations at sea, viz, on December 7, 1907, during a period of absolute calm, when even the long swell had almost died out, in latitude 22° 40′ south and longitude 170° 36′ east. A small skiff was put overboard, and the writer, assisted by Observer D. C. Sowers, rowed out about 100 yards from the ship. The Elster-and-Geitel flame collector was set up on its ebonite rod, at a height above sea-level estimated at 2 meters. Large, and extremely variable, potentials were obtained, varying rapidly from zero to potentials beyond the range of the electroscope. The mean value would be not far from 90 volts per meter. The conditions on this day were so abnormal that not much value can be assigned to the observations, though they encouraged the assumption that the potential-gradient over the sea is not so very different from that over the land.

It was hoped to investigate the amount of radioactive material in the atmosphere by Elster and Geitel's method. In this method a wire of definite length is charged to a potential of $-2{,}500$ volts and exposed to the atmosphere for a period of two hours, after which it is quickly coiled on a frame and introduced into an ionization chamber connected to an electroscope. If the ionization chamber and electroscope are of the proper capacity and dimensions, the activity is said to be unity when the initial fall in volts per hour per meter of wire introduced is unity. Owing, however, to breakage in the box of dry piles in transportation and the consequent failure of the means of maintaining a high potential on the charged wire, the radioactivity work was not satisfactory, as it was not found possible to reach a potential much above 1,000 volts, even with the box of dry piles opened to the hot sun. However, several exposures of a copper wire about 10 meters long were made during the first half of the voyage. In the neighborhood of land, as off the coast of Alaska and in Cook Strait, New Zealand, December 21, 1907, the observations showed conclusively the presence of radioactive emanation in the air, even with the low potential available for charging the wire. In Cook Strait a value for A (the "Aktivierungszahl" of Elster and Geitel) of 40 was found, the deposit decaying to half value in about 40 minutes. But in the open sea no increase in the rate of discharge of the electroscope used for testing the exposed wire could be detected. With a better charging device it might be possible to obtain some result, but it would probably be only a small fraction of that on or near land.

[1]See *Terr. Mag.*, vol. 13, pp. 119-128, 1908.

Rain-water, caught as it fell and immediately evaporated to dryness, showed no sign of radioactivity. The electroscope readings were always difficult, and not of sufficient accuracy to detect extremely small effects. The electroscope was always placed so as to allow the leaves to swing in a plane parallel to the length of the ship, so as to eliminate the effect of rolling as far as possible, but the leaves were never quiet and their mean position had to be estimated.

The only really satisfactory instrument for regular use on board ship was the Gerdien apparatus for determining the specific conductivity of the air. An Ebert ion-counter was also included in the outfit, but its leakage was too great and the time necessary for a single determination too long, so no results were obtained with it.

The Gerdien conductivity apparatus was the same as used by J. E. Burbank in his work in Labrador during the eclipse of 1905.[1] A uniform current of air is drawn by means of a fan through a cylindrical condenser, the inner cylinder of which is connected with the leaves of an aluminum-leaf electroscope. The outer cylinder is 16 cm. in diameter and 35 cm. long, while the inner cylinder is 1.4 cm. in diameter and 24 cm. long. The capacity is 12.9 cm. The inner cylinder being charged to a known potential, read on the electroscope, air is drawn through for a measured interval of time, usually 5 minutes. The ions of opposite sign to the charge on the cylinder will be attracted to it from the air passing by, and a certain portion of the charge will thus be dissipated. Only those ions will reach the inner cylinder which have sufficient velocity to carry them across the intervening space before they are carried by. The number of ions reaching the inner cylinder is practically independent of the velocity of the air-current so long as it is sufficient to prevent saturation currents from being established, and it is only necessary to insure that the velocity does not fall below a certain minimum value. Knowing the capacity and dimensions of the instrument and the time during which the air-current has been passing, the specific conductivity of the air can be computed from the potential of the inner cylinder at the beginning and the end of the exposure.

The instrument was at first mounted on a ship gimbal-stand, which was placed on top of the forecastle, under the observing bridge for magnetic observations, and for one-half of the voyage the observations were made at that place. The location was, however, not satisfactory on account of the neighborhood of the galley smokestack, smoke from which often reached the instrument during calms or while sailing by the wind. Accordingly, on the cruise between New Zealand and Peru (on February 3, 1908) the gimbal stand was moved to the main deck, just forward of the main hatch and still under the bridge. Here there was no further trouble from smoke.

The measurements of the specific conductivities λ_+ and λ_- for positive and negative ions gave as means[2]

$$\lambda_+ = 1.603\times10^{-4} \text{ E.S.U. (from 258 observations)}$$

$$\lambda_- = 1.433\times10^{-4} \text{ E.S.U. (from 260 observations)}$$

$$\frac{\lambda_+}{\lambda_-} = 1.12$$

The barometric pressure apparently affects the conductivity, as the mean values for λ_+ and λ_- for 34 days with the pressure below 762.0 mm. are 1.61×10^{-4} E.S.U. and 1.46×10^{-4} E.S.U., respectively, while for 24 days with the pressure 762.0 mm. or above, the mean values for λ_+ and λ_- are 1.52×10^{-4} E.S.U. and 1.31×10^{-4} E.S.U. respectively. High barometer apparently causes a decrease of conductivity. This may, however, be due to the fact that the low barometric readings were nearly all within the tropics, while the high

[1] See *Terr. Mag.*, vol. 12, pp. 97–104, 1907, for description of instrument.

[2] The original report contains also the complete tables of the individual values.

readings were in higher and lower latitudes, so that the effect may be regional rather than directly due to the pressure.

It is of interest to note that the ratio $\frac{\lambda_+}{\lambda_-}$ is considerably above unity. This condition was found to hold pretty consistently, and in regions of steady winds and settled weather the ratio was almost invariably above unity. In view of the fact that no measurable amount of radioactive deposit could be collected on a negatively charged wire while out in the open sea, it seems impossible to explain the value of the ratio, as has been attempted, by ascribing the greater rate of dispersion of a negative charge to the ionizing effect of the deposit collected on the negatively charged inner cylinder.[1]

OBSERVATIONS ON CRUISE I OF THE CARNEGIE, 1909–1910.

(W. J. PETERS IN COMMAND.)

Observations for specific conductivity and radioactive content of the atmosphere were taken on the portions of Cruise I of the *Carnegie* (see Fig. 15) from Falmouth to Madeira, Madeira to Bermuda, and Bermuda to New York. The extracts on pages 367–369 are taken from the report of the observer, Edward Kidson.[2]

FIG. 15.—Cruise I of the Carnegie, 1909–1910.

[1]See Kurz, Dissertation zur Erlangung der Doktorwürde, Giessen, 1907.

[2]See *Terr. Mag.*, vol. 15, pp. 83–91, 1910.

The conductivity observations were taken with the Gerdien conductivity apparatus described in P. H. Dike's report on the third cruise of the *Galilee*,[1] and the apparatus, when in use, was placed on a gimbal stand amidships, between the after observatory and the mainmast.[2]

Observations of temperature and humidity by means of a psychrometer, and of the air pressure, wind, clouds, and state of the sea, were made during the experiments. Observations for natural leakage were made at intervals; this seemed usually to decrease to a very low value during the observations, and no correction for leakage was applied.

The mean values of the conductivities λ_+ and λ_- for positive and negative ions, and of the ratio $\frac{\lambda_+}{\lambda_-}$ are as follows:[3]

$$\lambda_+ = 1.85\times10^{-4} \text{ E.S.U. (from 26 observations)}$$
$$\lambda_- = 1.58\times10^{-4} \text{ E.S.U. (from 26 observations)}$$
$$\frac{\lambda_+}{\lambda_-} = 1.16$$

From the observations obtained, no connection could be established between atmospheric pressure, humidity, wind, or cloud, and the conductivity. When, however, there was a visible fog or haze the conductivity was greatly reduced. This was noticed in some preliminary practice experiments at Falmouth and in Long Island Sound. Rain squalls of short duration did not produce any effect. As the conductivity is an extremely variable quantity, a very large number of observations is required before the connection with meteorological conditions can be thoroughly investigated. One effect noticed was that a low conductivity was invariably obtained when the vessel was in the neighborhood of land. This effect was heightened in Long Island Sound by the state of the atmosphere, and probably by the presence of snow on the land and ice on some stretches of water.

Another noticeable fact is the persistent excess of the positive conductivity over the negative. The only occasions on which the reverse appeared to be consistently the case were while the ship was at anchor off Madeira and in Hamilton Harbor, Bermuda.

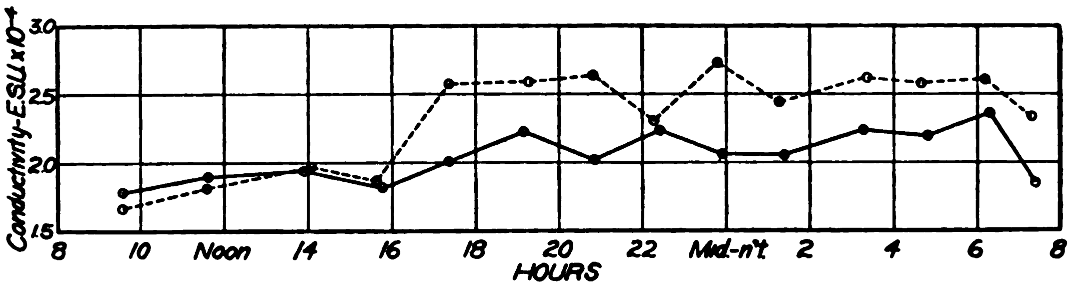


FIG. 16.—Conductivity of the Atmosphere, December 18–19, 1909.

On December 18–19, 1909, continuous observations of the conductivity were taken over practically 24 hours, in order to discover, if possible, a diurnal variation. The day was exceedingly calm and fine, with a glassy sea with a smooth, low swell. The results obtained are shown in Figure 16, the ordinates representing conductivities in E.S.U.$\times10^{-4}$. The continuous line corresponds to λ_-, the broken line to λ_+, and each point corresponds to the mean of from 4 to 8 observations. It will be seen that the observations indicate values of the conductivities which are higher by night than by day.

[1]See page 365.
[2]See description of the *Carnegie*, pages 160–163 and Plate 9, Fig. 2, Position E.
[3]The original report contains the complete tables of the individual values.

Observations on the amount of radioactive material in the atmosphere were made by Elster and Geitel's method.[1] Except on one occasion, the length of the collecting-wire was always 7 meters, and it was usually exposed for about 1 hour. While the collecting-wire was being exposed, the testing-electroscope was charged and the rate at which its potential fell noted, in order to measure the natural leak. The latter was almost invariably found to decrease with time, sometimes very regularly, and was generally nearly constant and small by the time the radioactivity test was begun. After the wire was inserted, the electroscope deflections were read at frequent intervals and the fall of the potential with time thus obtained. The results were plotted on cross-section paper, the ordinates representing potentials and the abscissæ times. A smooth curve was drawn through the points thus plotted, and from this smoothed curve an activity curve was drawn, the ordinate at any point of which was proportional to the gradient of the first curve at the time represented by the abscissa. The times were measured from the time of discharge of the wire.

On days when a comparatively large quantity of deposit was collected and the conditions of observation were good, the curves obtained for the decay of the activity were fairly regular and similar in character. The deposit appears to be derived from radium emanation. Table 73 shows roughly the relative amounts of activity collected on different days. The activity is here measured by the fall of potential in volts, produced in the electroscope, by the deposit in 1 hour, starting 15 minutes after the discharge of the wire. The capacity of the electroscope was about 15 cm.

TABLE 73.—*Relative Amounts of Radioactivity on the Carnegie's First Cruise.*

Date	Latitude	Longitude E. of Gr.	Time of Exposure	Activity	Remarks
1909	°	°			
Nov. 12	48.6 N	350.0	40 min.	40	Length of wire = 16 meters
14	46.5 N	345.7	100 min.	35	
20	40.2 N	342.1	1 hr.	75	
22	36.8 N	343.5	1 hr.	45	Potential too low
Dec. 3	28.0 N	341.0	1 hr.	60	
8	21.0 N	328.0	1 hr.	45	
11	20.8 N	322.6	30 min.	trace only	
14	20.5 N	318.0	1 hr.	20	
18	20.0 N	312.0	1 hr.	5–10	
20	19.8 N	310.5	1 hr.	35	
23	19.9 N	308.5	1 hr.	30	
26	21.6 N	305.2	1 hr.	20	
29	24.0 N	300.7	1 hr.	trace only	
1910					
Jan. 1	25.7 N	295.9	5 hr.	55	
4	28.5 N	292.8	10 hr.	30	
12	Hamilton, Bermuda		15 hr.	85	
May 14	Washington, D. C.		1 hr.	50	A. M.
16	Washington, D. C.		1 hr.	23	P. M.

On December 16, 1909, latitude 20°0 N, longitude 314°2 E, the wire was charged to a high positive potential for 1 hour, but no active matter appeared to have been collected.

On January 1, 4, and 12, 1910, the charged wire was exposed for a long period, in order to detect if possible the presence of thorium products in the atmosphere. On January 1, after 5 hours, there appeared to be still left on the wire about 3 per cent of the activity exhibited 10 minutes after discharging. This effect, however, may have been due to an increase of the natural leakage which was liable to take place in the increased dampness after nightfall. Unfortunately no determination of the leakage could readily be made at the close of this experiment. On the other two days no sign of activity could be detected after a few hours. On January 12, 1910, the observations were taken in Hamilton Harbor, Bermuda, under good conditions, so that a very slight activity should have been detected.

[1]See digest of P. H. Dike's report on the third cruise of the *Galilee*, page 364.

The mean values of the total conductivity, the ratio of the positive to the negative conductivity, and the relative potential-gradients are given in Table 74. It is to be remarked that only on one occasion during the whole cruise was a negative potential-gradient observed, although observations were made frequently while it was raining. Usually during rain the potential-gradient was very high, often exceeding the range which the electroscope would measure, but it was always positive. On the one occasion when a nega-

FIG. 17.—Cruise II of the Carnegie, 1910–1913.

tive potential-gradient was observed the sky was nearly covered with clouds, but there was no rain. Although the reduction factor for the potential-gradient was not measured on this cruise it is deemed safe to say that the observations indicate a mean potential-gradient of the order of magnitude of 120 volts per meter. The mean values of λ_+, λ_-, and λ_+/λ_-, for the whole cruise are respectively 1.61×10^{-4} E.S.U., 1.34×10^{-4} E.S.U., and 1.23. During the passage from Falmouth to New York, the observations of the radioactive content of the atmosphere formed a fairly complete set. The mean value for this cruise, of the activity, expressed in Elster-and-Geitel units, is 12.3, and the nature of the deposit on the wire was such that the activity decayed to half value in about 40 minutes.

It has been attempted to discover any relations which may exist between the various atmospheric-electric elements or between these and the various meteorological factors. As a rule, the relations which have been found agree with those which have been previously

which had probably passed over large bodies of land within a week. In the other group, designated "sea-wind," have been placed the remaining values of the conductivity which correspond to winds which had probably been blowing for a week or more over water. The sorting out was done independently by two persons, and Table 76 contains a summary of this analysis. One very large value of the conductivity has been omitted in this calculation.

TABLE 76.—*Effect of Land on the Conductivity at Sea.*

Group		$\lambda_+ + \lambda_-$ E.S.U.×10⁻⁴	No. of days involved
Land wind	1	3.17	124
	2	3.11	120
Sea wind	1	2.92	208
	2	2.94	203

The summaries in both Tables 75 and 76 support A. Nippoldt's view,[1] as based upon the *Galilee* observations in the Pacific Ocean in 1907–08, that the effect of the land is to increase the value of the conductivity as measured at sea.

From a summary of the various results thus far obtained at sea, the following deductions in regard to the mean values of the elements may be drawn: The potential-gradient is of the same order of magnitude over the sea as over the land; the radioactivity of the air over ocean areas far removed from land is small compared to that found over land, and the conductivity over the ocean is at least as large as that found over land.

OBSERVATIONS ON CRUISE III OF THE CARNEGIE, 1914.

(J. P. AULT IN COMMAND.)

The general course followed by the *Carnegie* during her third cruise is shown in Figure 18. The vessel left Brooklyn on June 8, 1914, arriving at Hammerfest on July 3. Sailing again from Hammerfest on July 25, she arrived at Reykjavik, Iceland, on August 24, having reached the latitude of 79° 52′ north, off the northwest coast of Spitzbergen. Leaving Reykjavik on September 15, the *Carnegie* arrived at Greenport on October 12, returning to Brooklyn on October 21, 1914.

The atmospheric-electric observations, which were made by Observer H. F. Johnston, comprise measurements of the potential-gradient, conductivity, and radioactive content of the atmosphere. In addition to these, a few observations were made in Long Island Sound by W. F. G. Swann, for the purpose of trying out certain new instruments and methods with a view to their adoption in subsequent ocean work. The following are extracts from W. F. G. Swann's report on the atmospheric-electric observations of the whole cruise. For the complete tables of observations, reference must be made to the original.[2]

As the first portion of the report contains a discussion of certain instrumental errors and corrections which will again be referred to in the account of the work on the next cruise, this portion of the report will not be abstracted here. The atmospheric-electric observations were always taken about the same time of day, between 9 a. m. and 12 noon.

Measurements of the potential-gradient were made by means of an ionium-collector suspended at the end of a bamboo pole which extended aft from the stern taffrail, and the standardization of the potential-gradient apparatus was made by simultaneous ship-and-shore observations on two occasions, the first at Reykjavik and the second at Gardiners Bay. In the shore observations a method due to Simpson was employed, in which the ionium-collector was fastened to the middle of a long wire stretched horizontally between two poles.

[1] *Terr. Mag.*, vol. 17, pages 33–41, 1912. [2] *Terr. Mag.*, vol. 20, pp. 13–48, 1915.

The conductivity observations were made with Gerdien's instrument, the electroscope being of the Wulf bifilar type. The radioactive content was measured by Elster-and-Geitel's method, with certain modifications devised with a view to rendering the results more susceptible of theoretical interpretation.[1]

In addition to the above, measurements of the ionic densities n_+ and n_-, for positive and negative ions, were made in Long Island Sound by means of the special form of ion-counter devised by W. F. G. Swann.[2]

The average value of the potential-gradient, atmospheric conductivity, and radioactive content for the whole cruise were, respectively, 93 volts per meter, 2.52×10^{-4} E.S.U., and 23. The last number is expressed in Elster-and-Geitel units. The average value of the air-earth current-density for the whole cruise was 7.7×10^{-7} E.S.U.

FIG. 18.—Cruise III of the Carnegie, 1914.

The observations, as far as they go, indicate a general increase of the potential-gradient from summer to winter, which is in accord with land observations for the daily mean values. The conductivity also shows a general increase from the beginning of the cruise (June 8, 1914) to about the end of September, when a maximum occurs, after which the conductivity falls; the air-earth current-density follows the general course of the conductivity. No very definite conclusions result as to the seasonal variations of the radioactive content, though the observations are not inconsistent with those of Simpson in Lapland, in

[1]See W. F. G. Swann, *Terr. Mag.*, vol. 19, pp. 176–179, 1914. [2]See pages 387–389.

indicating a higher active content in winter than in summer. Table 77 shows the mean values of the various elements arranged according to the period as given in the first column, λ_+ and λ_- referring, respectively, to the conductivities for positive and negative ions. The quantity q in the last column is proportional to the radioactive content of the atmosphere.

No marked variation of the atmospheric-electric elements with temperature or humidity was found; however, an indication is shown of a variation of the conductivity with latitude, a maximum for the latitudes involved occurring in the neighborhood of 50° north. These conclusions with regard to the variation of the elements with season, latitude, etc., must be looked upon as tentative, owing to the small number of data involved. A comparison has been made of the mean values of the conductivity for the several sections of the cruise, with the values to be expected as a result of the measured radioactive content.

TABLE 77.—*Atmospheric-Electric Elements Grouped According to Period of Year.*

Period, 1914	$\lambda_+ + \lambda_-$ E.S.U. $\times 10^{-4}$	$\frac{\lambda_+}{\lambda_-}$	Pot. grad. volt/m.	Air-earth current-density E.S.U. $\times 10^{-7}$	$q \times 10^{-4}$
June 18–June 25	2.24	1.21	75	5.6	62
June 25–June 30	2.43	1.12	90	6.8	109
July 27–Aug. 11	2.25	1.21	79	5.2	89
Aug. 12–Aug. 21	2.99	1.26	104	10.5	65
Sept. 15–Sept. 20	3.35	1.19	103	11.5	166
Sept. 20–Oct. 7	2.50	1.22	112	8.1	306

The results are given in Table 78. They have been calculated by reducing the measured radioactive content to Elster-and-Geitel units and then making use of an empirical relation obtained by Kurz for the rate of production of ions per cubic centimeter corresponding to 1 Elster-and-Geitel unit. In the table, q represents the rate of production of ions per cubic centimeter owing to the radioactive material, and the number of ions (n) per cubic centimeter of either sign has been calculated from the expression $n^2 = q/\alpha$, where α is the coefficient of recombination of the ions and is taken as 2.5×10^{-6}. The conductivity is taken as $2nev$, v being the specific velocity of the ions. The value of v has been taken as 1.3 cm. per second per volt per centimeter for each sign of ions.[1]

TABLE 78.—*Effect of Radioactive Material in Determining Ionization and Conductivity.*

Passage	q	$n_+ + n_-$ Observed	$n_+ + n_-$ Calculated	$\lambda_+ + \lambda_-$ Observed E.S.U. $\times 10^{-4}$	$\lambda_+ + \lambda_-$ Calculated E.S.U. $\times 10^{-4}$
New York to Hammerfest	0.41			2.00	1.51
Hammerfest to Iceland	0.50			2.00	1.6[illegible]
Iceland to Greenport	1.10			2.77	2.00
Long Island Sound, Oct. 19, 1914	1.64	822	1630		
Long Island Sound, Oct. 21, 1914	1.60	481	1520		

In the observations in Long Island Sound, n was measured directly for each kind of ion, and so it became possible there to compare the measured value of $n_+ + n_-$ with the calculated $2n$ without introducing the specific velocity of the ions. In the above calculated

[1] [illegible] In the original report the value 1.35×10^{-6} [illegible] Measurements on atmospheric ions have given varied results for a [illegible] In the general discussion of the results which forms part of the report on the [illegible] has been tentatively adopted. Again the results of the fourth cruise indicate [illegible] at the value 2.5 which was tentatively [illegible] The empirical relation obtained by Kurz has also suffered corrections at the hands of [illegible] For the sake of uniformity in relation to the discussion of the *Carnegie's* fourth cruise, [illegible] in Table 78 which depend upon theoretical constants have been recalculated in the light of the above [illegible]

values the effect of the penetrating radiation from the active material in the sea has been neglected; this effect is very small, however. It will be seen that while in the Atlantic Ocean the radioactive material is sufficient to account for an appreciable fraction of the conductivity, it is, on the basis of the constants used, insufficient to account for all of it. It must further be borne in mind that in so far as many of the ions produced by the radioactive material in the air undoubtedly go into the type of the slowly moving Langevin ions, the calculated conductivity should be even smaller; it is probably for this reason that the calculated values of $n_+ + n_-$ for the Long Island Sound observations come out greater than the observed values.

It is natural to expect a smaller radioactive content in the case of air which has been for some time over the ocean than in the case of air which has passed recently over land. If, then, making use of the wind records, we divide the days into two classes as regards the probable time which has elapsed since the wind last traveled over land, we should expect a higher radioactive content in the cases in which the wind has recently traveled over land than in the others. The conclusion is borne out in 8 of 9 cases during the voyage from New York to Hammerfest, and in the greater number of cases in the voyage from Iceland to Greenport. No very definite conclusion in this respect emerges from a consideration of the results of the voyage from Hammerfest to Iceland; but the winds on the voyage were usually of a very small velocity, and it is consequently difficult to form much idea as to the probable course which the air had pursued in the days preceding any one for which the strength is recorded.

In some cases, the conductivity appears to undergo an interesting change as one passes from the American shore out into the open sea. The conductivity starts considerably below its normal value, but increases again as one gets out into the open sea, a result observed also by E. Kidson[1] on the first cruise of the *Carnegie*. The values of the conductivity were particularly low in Long Island Sound.

Since both the conductivity and ionic content were measured in the Sound, it was possible here to deduce the specific ionic velocities, v_+ and v_-, for positive and negative ions. The mean values of v_+ and v_- so found are respectively 0.77 and 0.83 cm. per second per volt per centimeter. These values are somewhat below normal, a result which is in harmony with the low values of the conductivity in indicating abnormal conditions in the region of transition between sea and land.

The latter portion of the report is devoted to a mathematical discussion of the possibility of determining the nature and amount of active material in the atmosphere from an analysis of the decay curves for the active wire. It appears that the customary method of drawing conclusions as to the nature of the products in the atmosphere by comparing the decay curves for a wire exposed thereto with that of a wire exposed to emanation contained in a small closed vessel, is not justified. The activity curves are analyzed in the report, use being made of the theory of radioactive disintegration, and it is found that while some of the curves can be explained by radium emanation alone, others require the presence of a product of longer decay period than radium A, B, or C. The possibility of this extra product being a product of thorium emanation, as is generally assumed to be the case on land, is discussed.

An attempt to calculate the actual amount of radium emanation in the air directly from the theory of the Elster-and-Geitel method, without assuming any empirical relation, results in a much smaller value for the emanation content than that given by the empirical relation, unless it is assumed that the average specific velocities of the active carriers are much smaller than is generally supposed.

---

[1] See page 367.

OBSERVATIONS ON CRUISE IV OF THE CARNEGIE, 1915-1916.

(J. P. AULT IN COMMAND.)

The *Carnegie* started from Brooklyn on her fourth cruise March 6, 1915, stopping first at Gardiners Bay until March 9, to make her usual "swing observations," and arriving at Colon, Panama, on March 24, 1915. She next passed through the Panama Canal; leaving Balboa April 12, she sailed for Honolulu, arriving there May 21, 1915. She left Honolulu on July 3, and arrived at Dutch Harbor, Alaska, on July 20, from which port she sailed on August 4 for Port Lyttelton, New Zealand, arriving there November 2. Leaving Lyttelton December 6, 1915, a circumnavigation was made of the region between the parallels 50° and 60° south, the *Carnegie* returning to Port Lyttelton on April 1, 1916. On May 17, 1916, she again left Port Lyttelton bound for Samoa, Guam, and San Francisco. The cruise up to April 1, 1916, is shown in Figure 19.

FIG. 19.—Cruise IV of the Carnegie, 1915-1916 (April).

On the completion of the work of Cruise III it was felt, as a result of the experience gained, that the time had come when a more ambitious program of atmospheric-electric work could be undertaken with hope of success, and to this end the atmospheric-electric equipment was considerably increased. Also, a special atmospheric-electric house was built aboard the vessel for the more permanent installation of the instruments.

The design of the methods of measurement and the organization of the scheme of procedure in the atmospheric-electric work were initiated by W. F. G. Swann. In the work connected with the installation of the instruments aboard, and in the experimental work prior thereto, he was assisted by S. J. Mauchly and H. F. Johnston, the observer to whom had been assigned the atmospheric-electric work on the cruise. Swann and Mauchly accompanied the vessel from Brooklyn as far as Gardiners Bay, in order to complete the installations and tests of the new instruments. Mauchly continued with the *Carnegie* as far as Balboa to complete the remaining adjustments found necessary.

The observations from New York to Colon were made by Mauchly and Johnston. From Balboa (April 12, 1915) until the return of the vessel to Lyttelton, New Zealand, on April 1, 1916, after her sub-Antarctic circumnavigation cruise, they were made by Observers H. F. Johnston and I. A. Luke, and at the present time Observers B. Jones and I. A. Luke are carrying on the work.

The following account by Swann contains a description of the instruments and methods employed in the atmospheric-electric work, and a compilation and discussion of the data submitted in the reports of Mauchly and Johnston through March 1916.

ATMOSPHERIC-ELECTRIC QUANTITIES MEASURED.

In the choice of quantities to be recorded in any extensive series of atmospheric-electric measurements on the ocean, we must be guided by two main considerations. In the first place, the quantities should be such that, taken together, they form as complete a whole as possible. If we wish to discuss the variation of some quantity, such for example as the atmospheric conductivity, throughout the day, in order to compare the results with land values, it is desirable that we shall not omit to measure any quantity which we *know* to be a controlling factor in the determination of this element. Secondly, it is necessary that the quantities measured shall be such as can be obtained by apparatus which is adaptable to ocean conditions.

The atmospheric-electric quantities at present measured on the *Carnegie* are the following:

(1) The potential-gradient X.

(2) The conductivities (λ_+ and λ_-) arising from the positive and negative ions.

(3) The numbers (n_+ and n_-) of positive and negative ions per cubic centimeter.

(4) The number of pairs of ions produced per cubic centimeter per second in a closed vessel (the penetrating radiation).

(5) The radioactive content of the atmosphere.

(6) The radioactive content of the sea-water.

The meteorological observations which are made are: pressure, temperature, humidity, extent and nature of clouds, and strength of wind and its direction.

The diurnal variations of the potential-gradient, ionic-content, and penetrating radiation are also under investigation.

The conductivities are related to the numbers of ions per cubic centimeter by the expressions $\lambda_+ = n_+ e v_+$, and $\lambda_- = n_- e v_-$, where e is the electronic charge, and v_+ and v_- are the velocities under unit field, of the positive and negative ions respectively. Since $\lambda_+/n_+e = v_+$ and $\lambda_-/n_-e = v_-$, measurements of λ_+ and λ_-, n_+ and n_- lead directly to the determinations of v_+ and v_-.

The simultaneous measurement of conductivity and potential-gradient enables us to calculate, if we wish, the value of the vertical conduction current-density, which is

$$i = (\lambda_+ + \lambda_-)X$$

The primary interest attaching to the measurements of the radioactive content and of the number of pairs of ions produced per cubic centimeter inside a closed vessel lies in the

fact that it is to the radioactive material in the atmosphere and to the cause which is responsible for the production of ions in a closed vessel (the so-called penetrating radiation) that we must look mainly for an explanation of the normal atmospheric ionization. A further interest attaching to the measurements of the number of pairs of ions produced in a closed vessel arises from the fact that the formation of such ions has always been more or less a mystery, which, in the case of land observations, is in part to be explained by the γ-ray radiation from the radioactive materials in the soil, a cause which has very little counterpart over the ocean.

In one sense, atmospheric-electric observations over the ocean are susceptible of a more uniform interpretation than is the case with those taken on land, for at sea we are not troubled with topographical features which vary from place to place.

INSTRUMENTAL APPLIANCES.

Among the chief difficulties associated with atmospheric-electric work at sea is that of overcoming the effect, on the instruments, of the motion of the ship, and of securing good insulation. One is practically debarred from the use of instruments of the quadrant type and is forced to confine himself to electroscopes. The electroscopes in use on the *Carnegie* are of two types, the bifilar electroscope designed by Wulf,[1] and the single-fiber electroscope of Einthoven, modified according to the Wulf pattern.[2] In each of these instruments the restoring force, which resists the motion of the fibers or fiber under the action of the electrical forces, is brought about by the tension of a quartz bow, so that the indications of the instruments are affected to a comparatively small extent by the motion of the ship.

It will be recalled that in the bifilar instrument the gold leaves of the older forms of electroscope are replaced by platinized quartz fibers. The fibers are soldered at their upper ends to the main terminal of the instrument and at their lower ends to the mid-point of a quartz bow whose ends are fixed to a frame. When the fibers are charged they repel each other, and the resulting motion, which can be read by a microscope with a scale in the eyepiece, is resisted by the quartz bow. This type of instrument is useful where a sensitivity in the neighborhood of 0.5 division per volt is required. Further, the case of the instrument is double, and the inner part is insulated, so that by raising or lowering its potential, by means of batteries, the readings of the electroscope can always be brought to the most uniform part of the scale. The subsidiary case has an additional advantage in enabling the electroscope to be used for any desired range of potential.

In the single-fiber electroscope, a single platinized quartz fiber is attached at its lower end to a quartz bow and at its upper end to the main terminal of the instrument. Two insulated metal plates are mounted with their planes parallel to each other and to the quartz fiber, one plate being mounted on each side of the fiber. The case of the instrument being earthed, these plates may be charged to say +100 volts and −100 volts respectively, or to any convenient amount, by means of constant batteries, and charges communicated to the fiber will then cause a deflection. The deflection for a given potential applied to the fiber increases with the field between the plates and with diminution of tension on the fiber, which latter may be varied by moving the bow support up and down by means of a suitable screw. In the laboratory it is not difficult to secure a sensitivity of 100 or more eyepiece divisions per volt, but on board ship a sensitivity of from 5 to 10 divisions per volt is found more desirable.

For the batteries which determine the potentials of the plates of the Einthoven instrument, small groups of cadmium cells (Krüger batteries) are generally recommended. Unfortunately these batteries are liable to show sudden fluctuations in voltage, which, though of small amount, are sufficient to cause erratic movements of the fiber of the electroscope. The resistance of a 100-volt Krüger battery is very high, about 100,000 ohms, and

[1] *Phys. Zeit.*, vol. 8, pp. 246 and 527, 1907. [2] *Phys. Zeit.*, vol. 15, pp. 250–254, 1914.

POTENTIAL-GRADIENT.

In former work on the ocean, the potential-gradient has almost invariably been measured by some method such as the following: A bamboo pole extends from the stern rail of the ship and carries at its end a metal plate which is insulated and covered with some form of radioactive material, usually ionium. Under these conditions, the air in the vicinity of the plate is rendered conducting, and the plate itself takes up the potential of this air as determined by the electrical field of the Earth modified by the presence of the ship, bamboo pole, etc. An electroscope serves to measure the difference of potential between the ship and the disk, or collector as it is called, and this quantity is proportional to the potential-gradient. In order to obtain absolute values, it is necessary to secure simultaneous ship and shore observations, the latter being made over a flat surface by some apparatus which does not itself distort the field, and which measures the true potential-gradient.

The chief disadvantage associated with the use of a collector lies in the slowness of its action, which necessitates very perfect insulation if accurate results are to be obtained. Thus an ionium collector may require something of the order of two minutes to attain a potential within 1 volt of its final steady potential. It will be obvious that since in the final state there is a difference of potential of the order of 200 or 300 volts between the collector and the earthed bamboo pole, the final potential of the collector can not have its proper value unless the insulation is perfect. It will have a value somewhere between zero and the proper value, and determined by the fact that the current of electricity flowing from the collector to earth over the leaking insulation is equal to the current which is able to flow from the air to the collector, due to the latter being at a potential below its proper amount. A simple calculation will show that even the electrical dispersion from the wire leading to the collector is sufficient to maintain the potential below its proper value by an appreciable amount. Thus to consider an example, suppose V represents the amount by which the collector differs from the potential which it would finally attain in the absence of leakage due to dispersion or other causes. If c is the capacity of the insulated system, and V_0 the value of V when the collector is earthed, then in the absence of leakage,

$$-c\frac{dV}{dt}=kV$$

where k is a constant. Hence

$$V=V_0e^{-\frac{kt}{c}} \tag{1}$$

If, in the absence of leakage, the collector takes 1 minute to attain a potential within $V_0/100$ of its final value, we find from (1), $k/c=0.08$.

Thus, if, owing to the dispersion, the maximum potential differs by δV from its proper value, the quantity of electricity coming to the wire per second is $k\delta V=0.08c\delta V$. If δV were zero there would be no surface density of charge on that portion of the wire leading to the collector, which was near the collector, but the surface density would not be zero on portions of the wire remote from the collector. If C is the capacity of the wire and we write $CV_0/2$ as the total charge on the wire, we shall probably underestimate it. In this case, the rate of supply of electricity to the wire by dispersion would be[1] $4\pi CV_0\lambda_+/2$. Hence

$$0.08c\delta V=2\pi CV_0\lambda_+$$

Putting $\lambda_+=10^{-4}$, and observing that C/c would not be far from unity unless the electroscope had a considerable capacity, we find that, in the steady state, δV forms about 1 per cent of V_0. Thus if V_0 were 200 volts there would, in the case cited, be an error of 2 volts. It is true that this is not very much, but remembering that it is accounted for by the mere dispersion from the wire, we see how seriously the results would be affected by faulty insulation.

[1] See W. F. G. Swann, *Terr. Mag.*, vol. 19, pp. 81–84, 1914.

Another disadvantage attending the use of any form of collector shows itself from a consideration of the fact that since the electric force near the stern of a ship is a function not only of the electric force in the open, but of the configuration of that surface which is bounded by the sea and the stern of the ship, the force must be a quantity which fluctuates continually as that configuration changes, due to the rolling and pitching of the vessel. In order that potential-gradient measurements shall have a definite meaning, it is therefore desirable that they shall always be taken at one position of the tilt of the ship.

The apparatus devised for observations on the *Carnegie* was designed with a view to overcome the above objections. A picture of it is shown in Plate 22, Figure 4, and the principle of its action will be clear from Figure 20. The instrument is a modification of an earlier one[1] designed for preliminary use on the third cruise of the *Carnegie.* It comprises a brass tube A fixed at one end to an axle so that it can rotate in a plane containing the fore-and-aft line of the ship. The axle is mounted on supports fixed to the stern rail of the ship, and the projecting end of the brass tube carries a gauze disk B made somewhat in the form of a parasol. The handle C by which the rotation is brought about is insulated from the axle, and the latter is itself insulated from Earth by causing it to work in brass tubes fixed into their supports with sulphur insulation. The axle is connected by a thin wire to a Wulf bifilar electroscope D, the wire and axle being in the same line. It is arranged that when the brass tube is approximately vertical and the parasol attachment downward, the electroscope system is earthed. On rotating the tube to some other position fixed by a stop, a deflection proportional to the potential-gradient is obtained in the electroscope. Insulation difficulties are entirely overcome, since the leak occurring during the turning of the handle from one position to another is negligible; further, the operation can be performed so quickly that a reading can be obtained at any desired position of tilt of the ship. The sensitivity is considerable, and it is easy to arrange so that, for the normal value of the potential-gradient, deflections amounting to the whole scale length are obtained.

FIG. 20.—Diagram of Potential-Gradient Apparatus.

Although the principle of the apparatus is such that a high degree of insulation is not essential, the sulphur supports for the axle were provided with caps holding attachments for drying material. It has, however, not been found necessary to use any drying material; and indeed, during the whole period in which the apparatus has been in use on Cruise IV, hardly any occasion has been recorded in which insulation trouble was experienced with this instrument, although observations were frequently taken under conditions of great dampness. The arrangements are such that the parasol attachment can be fixed in position or removed in a moment, and this is the only part of the apparatus which is taken away when the observations are completed. The axle and electroscope system remain in position and are covered with a suitable cover. Two leads from a battery stored in a room some distance away come up to the base of the instrument, and enable a potential to be applied to the subsidiary case of the Wulf electroscope, so that the range of the instrument may be adjusted to suit special conditions. This arrangement also enables the sign of the potential-gradient to be determined by noting the direction of movement of the deflected fibers when a small potential of known sign is applied to the subsidiary case.

[1]See W. F. G. Swann, *Terr. Mag.*, vol. 19, pp. 183–185, 1914.

It is, of course, necessary to determine the reduction factor by which the indications of the instrument must be multiplied in order to reduce them to the corresponding values of the potential-gradient over a flat surface. In order to simplify matters, it is always arranged that, as for as the essentials which affect the potential-gradient observations are concerned, the configuration of the sails during observations is one of three specified types. One of the chief requirements for the determination of the reduction factor is that of obtaining a flat stretch of land, and in this matter careful judgment is necessary. It is essential to bear in mind that flatness of the ground in the immediate vicinity of the apparatus is not sufficient to prevent distortion of the field by distant topographical irregularities of large size. Thus, to give an example which will illustrate the general nature of the considerations involved, suppose the apparatus is situated between two parallel mountain ridges of semicircular cross-section. It can readily be shown that, if the mountain ridges are sufficiently far from each other, each acts as a linear doublet of moment $M = \frac{1}{2}Xa^2$ per unit length, where X is the electric field and a the radius of the semicircle. At a point midway between the ridges the alteration in the field due to the ridges would amount to $2(2M/r^2) = 2Xa^2/r^2$, where r is the distance from the center of one ridge to the point of observation. Hence, to consider a somewhat drastic case, if the tangent of the angle subtended by the top of the ridge were 0.2, there would be an error of 8 per cent in the measured potential-gradient. The error would obviously be the same for two ridges, each 1 mile high and 5 miles distant, as for two ridges 1 foot high and 5 feet distant.

For the actual shore observations it is desirable to choose a piece of ground which is practically on a level with the surface of the sea, and is free from trees. In the method[1] which has been used for the shore observations, a wire several meters long is suspended horizontally from two posts by suitable insulators, and a collector is attached to its center. The wire is connected to an electroscope at one end and simultaneous readings are then taken with this apparatus and with the apparatus on the ship. Since the wire which supports the collector lies in a horizontal plane, it does not acquire any charge, and so does not disturb the field; and for the same reason it does not contribute to leakage through atmospheric dispersion.

One of the chief sources of uncertainty in the determinations of the reduction factors arises from the fact that it is usually impossible to get the ship nearer to the shore station than half a mile; and it appears that if clouds are at all prominent, the ratio of the potential-gradients on ship and on shore is by no means constant. For this reason it is felt that the reduction factors should be measured as often as possible when favorable opportunities arise, so that by taking the mean factors obtained under different conditions, and in different localities, the importance of unknown irregularities will be reduced.

The daily observations of the potential-gradient are taken over periods of about half an hour, and, as far as possible, are arranged to extend over the middle period of the determination of the ionic content and conductivity. The example on page 397 illustrates the method of recording the observations.

CONDUCTIVITY.

In the measurement of each of the elements, conductivity, ionic content, penetrating radiation, and radioactive content, there is involved, in some part of the work, a determination of the rate of loss of charge by some insulated system connected to an electroscope, and usually several determinations of the quantity have to be made. It is customary in such cases to read the indications of the electroscope at equal intervals of time, and then deduce the desired results by making use of a calibration curve. This method has certain disadvantages; one has either to rely on the constancy of the calibration curve, a procedure

[1]See G. C. Simpson and C. S. Wright, *Proc. R. Soc.* A., vol. 85, p. 182, 1911.

not very desirable in the case of the Einthoven electroscope, or he must make a fresh calibration curve each day. Again, the computational work involved in the construction and use of such curves is considerable when much work has to be done. For these reasons the general principle has been adopted of always noting the time taken by the fiber of the electroscope in passing between two fixed readings on the scale of the electroscope. The electroscope system is in each case connected to a potentiometer system used in connection with a voltmeter, so that the electroscopes may be charged to any desired potential. On the completion of the main observations the fixed readings referred to are reproduced, by charging the electroscope with the potentiometer, and the corresponding readings in volts are read off from the voltmeter. This throws the constancy of indications on the voltmeter, an instrument which, both as regards the stage of its development and the nature of its

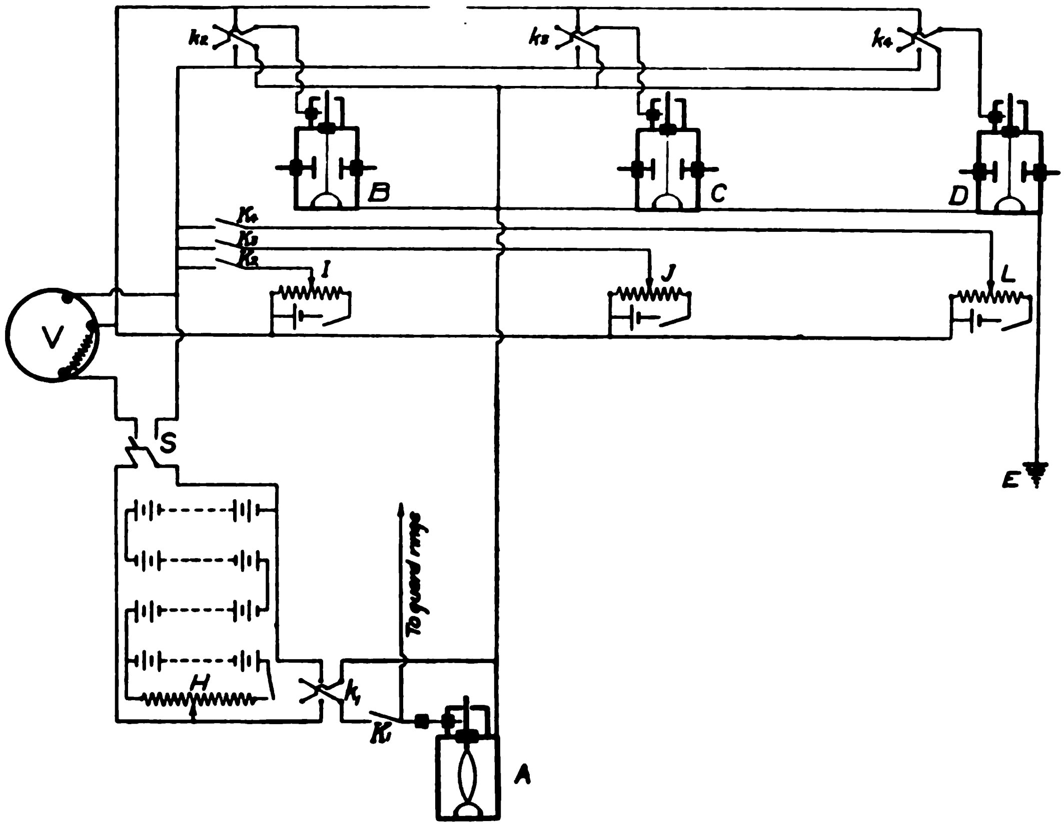


FIG. 21.—Wiring Scheme for the Atmospheric-Electric House on the Carnegie.

design, is such as to maintain a higher degree of constancy than is required in atmospheric-electric work. The voltmeter used is a minature Weston instrument, with ranges of 3 volts and 150 volts, and the potentiometer system is obtained by utilizing an adjustable resistance. Theoretically one potentiometer system would be sufficient for all the electroscopes; but in view of the difficulty of even standing still when taking observations in a heavy sea, it is desirable to put the matter of convenience of manipulation in the foreground, and a separate potentiometer system is attached to the base of each of the four electroscope systems in use in the observatory. Only the voltmeter is common to all the systems, and this is fixed to the wall in a position convenient for observation from all parts of the room.

Figure 21 gives a diagrammatic sketch of the wiring arrangements for the potentiometer systems. A, B, C, and D are the electroscopes for the conductivity apparatus, ion-counter,

penetrating radiation apparatus, and ionization chamber of the radioactive-content apparatus respectively. H, I, J, and L are the corresponding potentiometer systems, V is the voltmeter, and E is an earthed connection. The keys K_1 and k_1 serve to connect A to the potentiometer, K_2 and k_2 serve for B and so on. The reversing switches, k_1, k_2, k_3, k_4, enable the electroscopes to be charged with either sign of electricity. Since the electroscope A requires, as we shall see, the 150-volt range on the voltmeter, it must be separated therefrom by a separate switch S. The operation of the system will be clear from the figure, and it will not be necessary to describe it in greater detail. The electroscope systems are suspended from gimbals and each is provided with a small glow lamp and switch for use at night, and a spirit-level of convenient sensitivity. It is possible by means of the levels to guide the instruments by hand so that they are sufficiently vertical when readings of the electroscopes are made.

The method which is usually employed for measuring the conductivity of the air is that due to Gerdien. In this method air is drawn by a fan through the space between two concentric cylinders, the central member of which is charged and connected to an electroscope. The theory of the instrument shows that so long as the velocity of the air-current is large enough to insure that the central cylinder is unable to extract from the air all of the ions which it attracts as the air passes through, the rate of loss of charge by the cylinder is independent of the air velocity. It depends only upon the conductivity contributed by the ions of sign opposite to the charge on the central cylinder. Under these conditions, treating the apparatus as portions of length l of two infinitely long concentric cylinders of internal and external radii r_i and r_e respectively, Gerdien deduced the expression[1]

$$4\pi\lambda\left\{\frac{l}{2\log r_e/r_i}\right\}=\frac{C_1}{T}\log\frac{V_1}{V_2} \tag{2}$$

for the unipolar conductivity λ corresponding to the particular sign of ions involved. In this formula C_1 is the capacity of the whole apparatus, including the electroscope, and T is the time taken for the potential of the central cylinder to fall from V_1 to V_2. This formula is inaccurate in that it neglects the finite extent of the cylinders and more particularly the influence of the rod supporting the central cylinder. If, however, the quantity $l/2\log(r_a/r_i)$, which here corresponds to the capacity of the concentric cylinders under the above assumptions, be replaced by the *measured* capacity C_2 of the concentric cylinders, including the portion of the supporting-rod which is exposed to the air-current, the formula becomes exact[2] in the form

$$4\pi\lambda C_2=\frac{C_1}{T}\log\frac{V_1}{V_2} \tag{3}$$

For since the rate of supply of electricity to the apparatus as a result of the conductivity of the air is $4\pi\lambda C_2V$,[2] we have

$$-C_1\frac{dV}{dt}=4\pi\lambda C_2V \tag{4}$$

which integrates to (3).

In the work on the *Carnegie* the potential drops are small, and the differential form (4) is the more convenient one for use. A formula allowing for leakage during the experiment can most conveniently be deduced as follows.

Suppose that the fall in potential of the insulated system in the small time τ is δV, corresponding to θ divisions alteration in deflection of the electroscope. Suppose, also, that the alteration of deflection in the same time, as a result of leakage, with no air-flow, is ϵ.

[1] *Terr. Mag.*, vol. 10, pp. 69–71, 1905 [2] See W. F. G. Swann, *Terr. Mag.*, vol. 19, pp. 81–88, 1914.

Then the total loss of electricity in the time τ is $C_1\delta V$, and the loss by leakage is $C_1\tau\delta V/\theta$, or if we call t the time which the apparatus would require to *leak* through the range δV, the leakage term is $C_1\tau\delta V/t$. Thus from (4)

$$C_1\delta V\,(\tau^{-1}-t^{-1})=4\pi\lambda C_2 V \tag{5}$$

A determination of t is made just before the first and just after the last of the determinations of τ corresponding to each set of observations for the unipolar conductivity, and the mean value t_m^{-1} of t^{-1} is used in the formula. It is easy to see that the mean of the reciprocals rather than the reciprocal of the mean should be used. In determining the leakage term it is desirable to make observations over a range of potential in the neighborhood of the midpoint of the small range δV, and the value substituted for V in (5) should be the mean value corresponding to this range.

FIG. 22.—Diagram of Conductivity Apparatus.

In order that the theory of the apparatus may apply properly, it is necessary that the air-flow shall be sufficiently great, and it is desirable that it shall take place for a longer period than is readily possible with clockwork devices. For this reason the fan is run by a small electric motor driven by a 30-volt battery. A diagrammatic view of the conductivity apparatus is shown in Figure 22. The supporting-rod A of the central cylinder rests in a brass socket fixed in the amber plug S, and the amber plug is contained in a brass tube supported from the brass wall BB by three brass struts. The upper part of the apparatus is inclosed by the box CC, the whole of which is above the roof of the observatory. To the bottom of the box is fastened a brass ring which can turn in a fixed ring screwed to the roof,

thus enabling the apparatus to be turned to the wind. The movable brass ring carries a gimbal system which supports the electroscope system, so that the latter remains vertical as the ship inclines. The wire W passes through a hole in a screw E in the amber piece G, and by adjusting the screw, coincidence can be secured between the point of intersection of the gimbal axes, and the point at which the wire bends as the ship inclines. It was ascertained experimentally that the change in configuration resulting from tilt was not sufficient to alter appreciably the electrical capacity of the system.

The air, after being drawn through the space between the cylinders, passes in the direction of the arrows P down into the observatory, whence it escapes from the windows at all parts of the room. Thus, air which has lost its conductivity in passing between the concentric cylinders is prevented from entering the apparatus again. The funneled opening H can be readily removed when observations are completed, and the apparatus may then be covered with the box seen in Plate 22, Figure 1, on the roof of the observatory to the right of the figure. During leakage tests, the entrance to the concentric cylinders is closed by a wooden disk and the exit by a shutter O.

It will be seen that the main source of leakage in the apparatus is across the amber supports S and G, Figure 22. Quite recently these supports have been replaced by two insulators, each of which is divided into two parts by a guard-ring R maintained at the potential to which the electroscope is charged at the beginning of the observations. Thus leakage occurs only as a result of departure from that potential, and hence is very small. The electroscope itself is not provided with a guard-ring, but its insulation can be protected more thoroughly than that of the amber supports S and G.

The method of recording the observations and of calculating the results will be understood by a reference to the example on page 398. One determination of (say) λ_+ is made as indicated in the example, and comprises two observations of τ. This is then followed by a determination of λ_-, comprising 4 observations, and finally by another determination of λ_+ comprising 2 observations.[1] The mean of the two values of λ_+ is then taken as the value appropriate to the mean time of the whole experiment. Days on which there were 2 determinations of λ_- and 1 of λ_+ alternated with those on which there were 2 determinations of λ_+ and 1 of λ_-. The conductivity observations were carried on simultaneously with those of the ionic numbers in a manner which will be clear when the determination of the latter element has been described.

IONIC CONTENT.

The usual method of measuring the ionic content of the atmosphere is that due to Ebert. It will be remembered that in this method a stream of air is drawn by a fan through a cylindrical condenser, the inner cylinder of which is connected to an electroscope charged (say positively) to about 200 volts. If W is the volume of air flowing through the cylinder during the experiment, δV the fall in potential in that time, e the ionic charge, n_- the number of negative ions per c. c., and C the capacity of the whole instrument, then if the potential of the inner cylinder is sufficient to result in all the negative ions being caught, we have

$$n_- e W = C\delta V$$

One of the chief defects of the method is the fact that the time necessary to obtain a measurable alteration δV in the electroscope is rather long, amounting, according to some authorities, to as much as 30 or 40 minutes.[2] This not only accentuates errors due to leakage, but it introduces uncertainties owing to the variation of the ionic density during the time of the experiment. The reason for the slowness of the method of course lies in the

[1] Since the method of recording the observations is the same for each set, only one set is shown in the example on page 398.
[2] See G. C. Simpson and C. S. Wright, *Proc. R. Soc.* A, vol. 85, p. 188 1911.

fact that if we employ an electroscope which is to measure 200 volts on its scale, it obviously can not show very much movement for a small alteration of potential of say 1 volt.

In the apparatus which was devised to overcome the above difficulties[1] the central cylinder is connected to the fiber of a single-fiber electroscope which can be adjusted to any convenient sensitivity. For land observations a sensitivity of about 20 divisions per volt is convenient, but at sea a somewhat smaller sensitivity (about 5 to 10 divisions per volt) is more desirable. The potential of the fiber is never allowed to depart far from zero potential, and the necessary field is obtained by insulating and charging the outer cylinder to about 150 volts. On releasing the fiber from earth it, of course, starts to move, and the rate of movement can be noted. The leakage correction becomes reduced to a very small amount owing to the small departure of the system from zero potential during the experiment. In order to prevent the charge on the outer cylinder from affecting the number of ions coming to the apparatus, the cylinder is shielded by another cylinder separated from it by a thin hard-rubber ring. This latter cylinder is earthed, and as it takes a charge equal and opposite to that on the cylinder next to it, it to a great extent annuls the effect of that cylinder. It by no means does so completely, however, even when the two cylinders in question are separated by no more than 1 mm. We can easily see why this is so, for though it is difficult to estimate the exact distribution of forces around the mouths of the cylinders, we can easily see that since a point such as *F*, Figure 23, which is inside the charged cylinder, is at -150 volts, and a point such as *D*, which is outside, is at about zero, the ions which get inside will have to do so in opposition to a field corresponding to a fall of potential of 150 volts in a comparatively short distance. If the velocity of the air-current falls below a certain minimum value, obviously *no* ions will get inside. For the usual air-currents employed, however, the effect is to diminish the number of ions entering. This difficulty is one which shows itself very materially in practice, as appeared when experiments were made to test it; it is, however, completely overcome by the device shown in Figure 23, *A*.

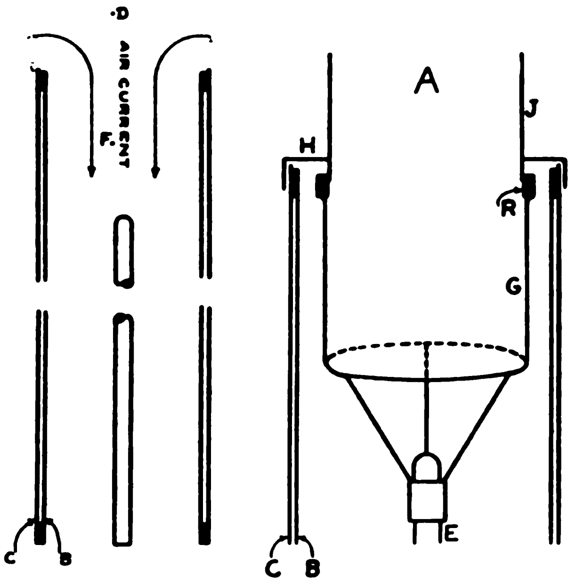


FIG. 23.—Diagram Illustrating Attachment to Upper End of Central Rod of Ion-Counter.

The figure shows the top end of the apparatus, *B* and *C* are the two outer cylinders, and *E* is the top of the central rod. *E* carries a collar attached to three wires which in turn support a thin hollow cylinder *G*. A cap *H* fitting over the entire end of the apparatus is fitted with a piece *J* which just goes inside the top of *G*, from which it is electrically separated by an amber ring *R*. This ring is fixed at the top of *G* on the inside, and is prevented from falling down by a little shoulder turned on the brass. By this arrangement *G* is kept from shaking, and it will be seen that air at zero potential outside can now get well inside without having to pass through a point different from zero. Any repulsive influence of the cylinder *B* on the ions as they come near the lower end of *G* can only result in their being turned sideways and caught by *G*, and this produces no error, since *G* is connected electrically to *E*.

[1]See W. F. G. Swann, *Terr. Mag.*, vol. 19, pp. 171–176, 1914.

The fan and air-meter attached to the apparatus are of the same type as those supplied by Messrs. Günther and Tegetmeyer, with the usual Ebert apparatus; the electroscope is, however, as already stated, of the single-fiber type, and is adjusted to a sensitivity of from 5 to 10 divisions per volt.

In Plate 22, Figure 2, to the left of the figure, are shown the electroscope system, fan, and meter. A box, containing the battery for the plates of the electroscope, is attached to the base of the apparatus, and the whole instrument is suspended from a gimbal system. The open end, which is shielded by a hood, projects through a hole in the roof of the observing-house.

In making the observations, the fiber is released from earth, and is allowed to move over a fixed range of the scale of the electroscope as in the conductivity observations, the meter readings during the transit of the two marks being noted. Apparent leakage may result from two causes, a true leak arising when the fiber departs from zero potential and small alterations in the potential of the battery during the experiment. The former effect, which is in general very small for the small potential increase of the fiber, is at any instant proportional to that increase, while the latter is independent of it. Provided, however, that the "apparent leakage" correction is determined when the fiber is charged to the mid-point of the fixed range, we need not concern ourselves with any distinction between the two types of effects.

If C is the capacity of the apparatus, and δV the magnitude of the fixed range, n the ionic density, e the electronic charge, and W the air-flow during the movement over the range δV, we have

$$C\delta V = neW + C\left(\frac{dL}{dt}\right)\tau$$

where τ is the time of duration of the observations, and $\frac{dL}{dt}$ is the rate of alteration of potential in the leakage experiment.

If t is the time which would elapse during the entry of $C\delta V$ units of electricity into the apparatus by apparent leakage, the potential being maintained constant, we have $C\delta V = neW + C\delta V\tau/t$, and if ω is the quantity of air which would flow through the apparatus in the time t, $\tau/t = W/\omega$, so that[1]

$$n = \frac{C\delta V}{e}(W^{-1} - \omega^{-1})$$

The procedure with regard to taking alternate readings for n_+ and n_- is exactly analogous to that adopted for the conductivity, and for each set the mean value of W^{-1} for the set is used in the formula, as also the mean of the values of ω^{-1} obtained at the beginning and end of the set. The results are recorded as in the example shown on page 398, the relation between the air-flow and meter-reading being obtained from data supplied with the meter. It will be noticed that the tables for recording the conductivity and ionic content bear a strong resemblance to each other, a fact of considerable advantage.

In view of the suspicion which naturally attaches to the indications of any small meter operating on the fan principle, arrangements have been made during the latter part of 1916 to recalibrate this instrument aboard ship from time to time.

Before making the leakage tests with the conductivity apparatus and the ion-counter, the fans are allowed to draw air through the instruments for 5 minutes, so that the insulating material may attain that degree of dampness which it will have during the experiment.

[1]It will be observed, from the mode of deduction of this formula, that, when the apparent leakage acts in the same sense as the ions entering the apparatus, ω is to be inserted as a positive quantity. In the usual case, however, where the leakage is a true one, ω is negative.

The fans are then stopped, and the first leakage tests are made simultaneously for the two instruments. The fans are then started again, the conductivity apparatus is charged to its appropriate potential, and the ion-counter fiber is released from earth. The time of passage of the right-hand fiber of the conductivity apparatus across its first fixed mark is then noted, and when the ion-counter fiber has reached its first mark the meter is read. When the ion-counter fiber has gotten to its second fixed mark the meter is again read, and, the fixed range for the conductivity apparatus having been previously chosen so that the fiber of this instrument is, by this time, approaching its second mark, the time is noted when that mark is reached. The conductivity apparatus is then recharged, the ion-counter is earthed, and the operation is repeated, and so on. In this way the observations of the ionic content are carried on simultaneously with those for the conductivity and so provide a means for determining the corresponding specific velocity, which is recorded on the same form as the conductivity and ionic content.

PENETRATING RADIATION.

For the measurement of this element a copper vessel of about 27 liters capacity is employed; it is provided with a central rod which is insulated from the vessel by an amber plug and connected to the fiber of a single-fiber electroscope. A potential of about 150 volts is applied to the vessel and the ions of the corresponding sign produced therein are driven to the central rod, so that on releasing the fiber of the electroscope from earth, it commences to move at a rate determined by the rate of production of the ions in the vessel. The principle of noting the time taken by the fiber in moving over a fixed range is adopted here as in the other instruments and the observations are recorded as in the example given on page 399. The quantity sought is, of course, the number of pairs of ions produced per cubic centimeter per second in the closed vessel.

The insulating plug which supports the rod is divided into two parts by means of an earthed guard-ring, so that, since the apparatus is not subjected to air-currents from outside, leakage may be taken as negligible. Indeed, leakage may be entirely eliminated by starting observations with the fiber charged in such a sense that it crosses the zero during the observations, for it may then be arranged that the fiber-readings which are chosen as the bases of the measurements lie at equal distances on each side of the zero. The copper vessel, which is hermetically sealed, was thoroughly cleaned on the inside before it was installed.

In order to avoid movements of the fiber of the electroscope resulting from variations of the potential applied to the large vessel, an additional attachment has recently been incorporated. This attachment comprises a cylindrical piece, which is in electrical connection with the central system, and is surrounded by an insulated hollow cylinder which does not touch it. Although the volume of the attachment is small, the capacity of the portion inclosed by the hollow cylinder is comparable with, and may be made nearly equal to the capacity of the portion of the rod surrounded by the large vessel. The two ends of a megohm are connected respectively to the large vessel and to the outer cylinder of the attachment, the mid-point of the megohm being connected to the case of the electroscope. A battery of 300 volts is also connected to the two ends of the megohm. It will be obvious that under these conditions, and when the capacities above referred to are adjusted to equality, fluctuations of the battery potential may take place without affecting the potential of the insulated system. The result is the same as if the battery did not fluctuate. In the laboratory, Swann has used this method with success for producing the equivalent of a battery constant to 1 part in 10,000,000 or more.

RADIOACTIVE CONTENT OF THE ATMOSPHERE.

In former work on the ocean, and in much of the work which has been done on land, attempts have been made to obtain relative estimates of the amount of active material in the atmosphere by the method devised by Elster and Geitel. This method suffers from various disadvantages in respect of the indefiniteness of the meaning to be attached to its results,[1] and even under the most favorable conditions it can not be said to afford a very satisfactory method of estimating the radioactive content.

Undoubtedly one of the best methods of determining the radium-emanation content of the atmosphere is that involving the absorption of the emanation from the air by charcoal, with a subsequent determination of the amount absorbed. The time required for this operation, however, and the nature of the apparatus necessary, is such as to render the method impracticable for use aboard ship. The method at present employed on the *Carnegie* consists in drawing air between two concentric cylinders, the central one of which is charged negatively to such a high potential that all of the active carriers entering the concentric cylinders are brought to the central system. The saturation current produced in an ionization chamber by the active deposit collected in a given time is measured. This, combined with a knowledge of the air flow during the collection of the deposit, enables the amount of active material per cubic meter of air to be estimated, if one assumes a knowledge of the nature of the deposit, which latter can be obtained from the form of the decay curve. The general principle of this method has been used, in one form or another, by several investigators on land, and the chief modifications introduced in the present apparatus have been made with the object of rendering the results more susceptible of accurate theoretical interpretation and of increasing the sensitivity of the apparatus and its adaptability for use at sea.

The collecting apparatus, as at present employed, is shown in its essential features in Figure 24. It comprises a copper cylinder *A*, 64 cm. long and about 20 cm. in diameter, with an anemometer at one end and a fan at the other. The central system consists of an insulated wooden cylinder *B*, 12 cm. long and 12 cm. in diameter, supported by a rod passing through its axis and insulated from it by sulphur, *S*. The surface of the wooden cylinder is covered with copper foil, held on by rubber bands, and it is on this foil that the deposit is collected. Earthed metal-caps *CC*, attached to the central rod, cover the top and bottom of the central cylinder without touching it, and insure that the negative charge, and consequently the active deposit, are confined to the copper foil.

FIG. 24.—Diagram of Collecting System of Radioactive-Content Apparatus.

A large air-current is necessary if a large amount of deposit is to be obtained, and in order to secure saturation with a reasonably low potential on the central cylinder, it is necessary that the latter shall be large. A large cylinder, when afterwards introduced into the ionization chamber, so as to form the central system there, would, however, on account of the large capacity, reduce the sensitivity in the ionization-chamber measurements. For this reason, the central system of the ionization chamber is formed of a thin rod, and the foil, after removal from the inner cylinder of the collecting apparatus, is bent over and made to line the walls of the ionization chamber, with the active surface facing inwards. In this way, the foil does not contribute to the capacity of the system. The height of the ionization chamber is about twice that of the foil cylinder, so that the latter only covers the middle portion of the wall of the chamber, and in this way it is insured that none of the α particles strike the top or bottom of the chamber. Thus, although the range of some of the

[1]See C. W. Hewlett, *Terr. Mag.*, vol. 19, pp. 146–148, 1914; also W. F. G. Swann, *Terr. Mag.*, vol. 19, p. 91, 1914; also *Terr. Mag.*, vol. 19, pp. 176–182, 1914; also *Terr. Mag.* vol. 20, pp. 18–22, and pp. 30–48, 1915.

α particles is cut short by their traversing, for example, a short cord of the cylinder, the average reduction of range brought about in this way is a definite and calculable function of the radius of the cylinder and of the true range of the α particles. It is independent of the distribution of the active material on the foil, a point of some importance, since the distribution of active deposit on the foil is by no means uniform.

The central system of the ionization chamber is attached to a single-fiber electroscope adjusted to a sensitivity of 5–10 divisions per volt, and the potential is applied to the outer vessel, the whole being mounted on a gimbal. The method of allowing for leakage is exactly analogous to that adopted in the case of the conductivity apparatus, except that it is not readily possible to make a leakage test at the end of the experiment, since the whole of

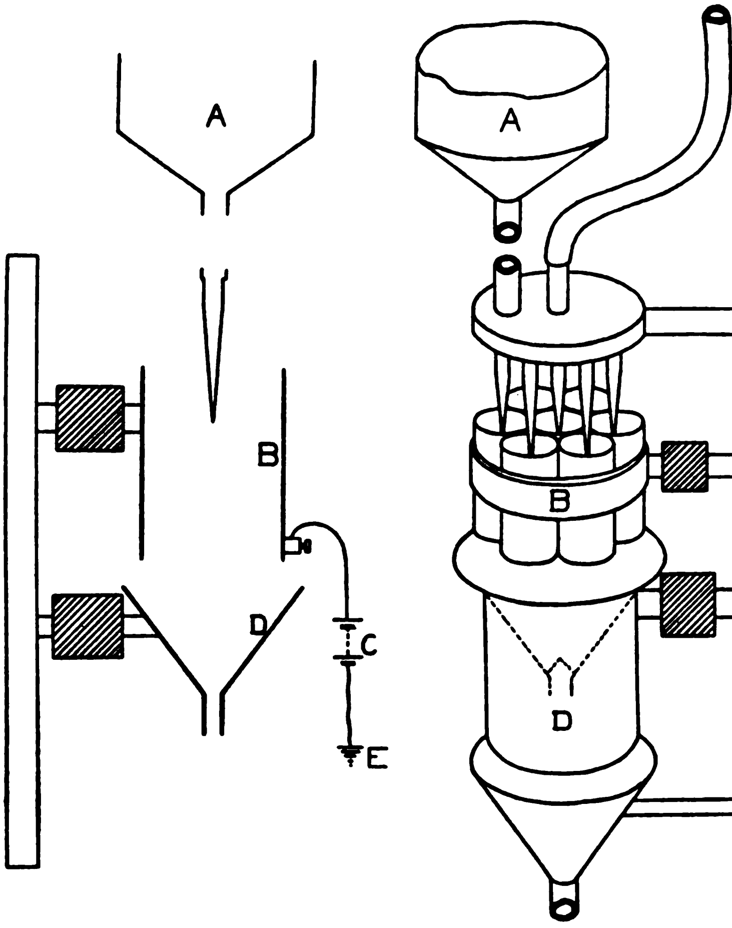


FIG. 25.—Diagram of Water-Dropper.

the internal surface of the ionization chamber is then likely to be covered with the disintegration products of the material originally collected.

A picture of the ionization-chamber system is shown to the right of Plate 22, Figure 2, and in Plate 22, Figure 3, will be seen the collecting apparatus with the outer cylinder removed so as to show the central system. The collecting apparatus is mounted by itself aft of the galvanometer house, and the fan for drawing the air is worked by a motor. For driving this motor and the one in the conductivity apparatus, a 30-volt battery of 300 ampere-hour Edison primary cells has been used, as it has not been practicable so far to install an accu-

mulator battery and charging system. The use of primary batteries renders it necessary to economize on the running of the motors and so the active deposit has been collected for only half an hour each day.

For charging the central system of the collecting apparatus a means of obtaining a potential of about 2,000 to 4,000 volts is necessary. Zamboni piles are not suitable for such work at sea, for they fall very considerably in potential unless the insulation can be maintained to a high degree in all parts of the apparatus. A form of Kelvin water-dropper multiplier has been found most convenient for the work in hand. Such an apparatus possesses the advantage that it is not permanently injured by short circuits or by subjection to faulty insulation for long periods. In the simplest form of water-dropper a tank A, Figure 25 (to the left), supplies water and forms a jet in a cylinder B, which is insulated and connected to one pole of a battery C, whose other pole is earthed. Under these conditions the funnel D and its attachments become charged by the falling drops, and in practice the potential of D rises until the rate of electrical leakage over insulating material, etc., equals the rate of supply of elecricity by the drops. The latter quantity can be increased by increasing the potential of the battery C, but to this there is naturally a practical limit. Very little is gained by simply increasing the number of jets in the cylinder, for the effect obtained is proportional to the electrical capacity of the droplets, and this quantity increases very slowly with increase of the number of jets when the latter are close together. If, however, the cylinder B is divided into a number of separate compartments, as in Figure 25 (to the right), and one jet is allowed to break in each compartment, the effect of the jets should be additive, and an apparatus of this kind was consequently designed for use on the *Carnegie*. Some tests carried out on this apparatus, by S. J. Mauchly, showed that the contributions of the jets were strictly additive, and the apparatus with 7 jets and a potential of 100 volts on the cylindrical compartments gave, on short circuit, a current of 105 E.S.U.

High potentials and relatively large currents can also be obtained by using Lord Kelvin's double multiplying system; but, for the particular work in hand, it was felt that the above method was much more suitable.

The air-flow is required in cubic centimeters per second, but the anemometer used with the apparatus reads in linear feet. Apart from this, however, the indications of an anemometer, when used in a tube as in the present experiment, are not related in a simple way to its indications in the open. It was consequently necessary to determine a reduction factor k, to reduce the apparent indications of the instrument to cubic centimeters per second.

To this end was constructed a dummy apparatus which, as far as essentials were concerned, was of the same geometrical form as the main apparatus. At the end remote from the anemometer were inserted three wire grids, of such a size as to extend right over the cross-section of the cylinder. The central grid, which was of manganin, served as an electrical heater, and the other two grids, which were of copper, functioned as resistance thermometers, and were used differentially. The energy supplied to the central grid was measured when the steady state had been attained, and this quantity, combined with a knowledge of the specific heat of air and the temperature rise between the outer grids, served to give the air-flow in absolute units. It was thus possible to calibrate the anemometer under the exact conditions in which it was used. The actual observations concerned in the determination of the factor k were made by D. M. Wise.

The observations are recorded as in the example shown on page 400. The quantity η represents the number of pairs of ions produced per second in the ionization chamber, due to the active material which would be deposited in an air-flow of 1 c. c. per second. η is recorded for various values of the time estimated from the completion of the deposition, and serves as a preliminary quantity for use in the subsequent determination of the radium-

emanation content. This determination, which necessitates a careful analysis of the curves obtained by plotting η against the time, is carried out at Washington, and is based on principles which will be clear from the following:

THEORY OF DETERMINATION OF EMANATION CONTENT OF THE ATMOSPHERE.

In attempts to calculate the amount of emanation in the atmosphere from an experiment depending on the collection of the active deposit, it is customary to assume that only radium A is deposited, although, of course, the fact that this radium A subsequently decays to radium B, and radium C on the wire is taken into account. It is to be remembered, however, that radium B and radium C are also deposited, and it turns out, in fact, that the decay curves for the active deposit can not be satisfactorily explained by supposing them to arise entirely from the radium A deposited. It might be thought that the products radium A, radium B, and radium C, in the present experiment, would be deposited in proportion to the equilibrium amounts present in the atmosphere, so that it would be an easy thing to calculate the shape of the decay curve from the theoretical constants of the substances. It must be remembered, however, that the A, B, and C products combine in part with the negative ions in the air, and to different extents, depending on their decay periods. Those particles which so combine naturally lose in the experiment their power of being deposited. Thus, in the equation of the decay curves in terms of the known radioactive constants, there must appear 3 constants, to be determined from the shape of the experimental curve, and representing the numbers n_a, n_b, and n_c of positively charged atoms of radium A, radium B, and radium C per c. c. of the atmosphere. When the value of n_a has been determined on the above lines, and in the manner to be described in greater detail below, the total number of atoms of radium A per c. c. of the atmosphere, including those atoms which have lost their charge, may be approximately determined by multiplying the value of n_a by the correcting factor $(1+an_-/\lambda_A)$,[1] where a is the coefficient of recombination of ions, and n_- the number of negative ions per c. c. of the atmosphere. Thus if E is the number of atoms of radium emanation per c. c. of the atmosphere, and λ_E the decay constant of the emanation, we have

$$E\lambda_E=\lambda_A(1+a\frac{n_-}{\lambda_A})n_a \tag{6}$$

Of if Q be the weight of radium with which the above amount of emanation would be in equilibrium, and if λ_R is the decay constant of radium, we have

$$Q=\frac{\lambda_A}{\lambda_R}n_a(1+a\frac{n_-}{\lambda_A})\ \ (3.7\times10^{-22}) \tag{7}$$

where 3.7×10^{-22} represents the weight of an atom of radium.

Such a procedure neglects any thorium emanation which may be present; but in view of the short decay period of thorium emanation there is small likelihood of the existence of any appreciable amount of this element far from land. It is also to be remarked that the time of deposition in the present experiments is so short that in any case the shape of the decay curve is mainly determined by the radium emanation.

[1] See J. Salpeter, *Wien. Ber.*, vol. 118, p. 1163, 1909, and vol. 119, p. 107, 1910.

The method of calculating, from the decay curve, the number of atoms of radium A, radium B, and radium C in the atmosphere, is analogous to that adopted in the case of the observations of the third cruise of the *Carnegie*.[1] The following notation will be adopted:

Let λ_A, λ_B, λ_C, be the decay constants for the A, B, and C products of radium emanation respectively; T the time of exposur

Let n_A be the number of atoms of radium A

Let n_B be the number of atoms of radium B

Let n_C be the number of atoms of radium C

Let t be the time at any instant after the foi the time $t=0$ being the instant when th

Let N_A be the number of atoms of radium A

Let N_B be the number of atoms of radium B

Let N_C be the number of atoms of radium C o

Let $\overline{N}_B$ be the number of atoms of radium B on the foil from radium A.

Let $\overline{N}_C$ be the number of atoms of radium C on foil at time t due to their formation on the foil from radium A via radium B.

Let $\overline{\overline{N}}_C$ be the number of atoms of radium C on foil at time t due to formation from the radium B deposited.

In the present work, T is 1,800 seconds, and the following values are adopted for λ_A, λ_B, and λ_C:

$$\lambda_A = 3.85\times10^{-3} \qquad \lambda_B = 4.33\times10^{-4} \qquad \lambda_C = 5.93\times10^{-4}$$

Proceeding on lines analogous to those indicated in Rutherford's "Radioactive Substances and their Transformations," pages 426–427, we obtain,

$$\lambda_A N_A = n_A(1-e^{-\lambda_A T})e^{-\lambda_A t} \tag{8}$$

$$\lambda_C \overline{N}_C = n_A\lambda_C(ae^{-\lambda_A t}+be^{-\lambda_B t}+ce^{-\lambda_C t}) \tag{9}$$

where

$$a=\frac{\lambda_B(1-e^{-\lambda_A T})}{(\lambda_B-\lambda_A)(\lambda_C-\lambda_A)} \qquad b=\frac{\lambda_A(1-e^{-\lambda_B T})}{(\lambda_A-\lambda_B)(\lambda_C-\lambda_B)} \qquad c=\frac{\lambda_A\lambda_B(1-e^{-\lambda_C T})}{\lambda_C(\lambda_A-\lambda_C)(\lambda_B-\lambda_C)}$$

We also find

$$\lambda_B N_B = n_B(1-e^{-\lambda_B T})e^{-\lambda_B t} \tag{10}$$

$$\lambda_C \overline{\overline{N}}_C = n_B(b_1 e^{-\lambda_B T} - c_1 e^{-\lambda_C t}) \tag{11}$$

where

$$b_1=\frac{\lambda_C(1-e^{-\lambda_B T})}{\lambda_C-\lambda_B} \qquad c_1=\frac{\lambda_B(1-e^{-\lambda_C T})}{\lambda_C-\lambda_B}$$

$$\lambda_C N_C = n_C(1-e^{-\lambda_C T})e^{-\lambda_C t} \tag{12}$$

If p, q, and r represent the number of ions produced by an a particle of radium A, radium B, and radium C respectively, then, remembering that radium B emits no a-particles, the total rate of production of ions which would take place in the ionisation chamber as a result of the deposit on the foil, if all the a-particles produced their full number of ions, is

$$\lambda_A N_A p + \lambda_C\overline{N}_C r + \lambda_C\overline{\overline{N}}_C r + \lambda_C N_C r$$

[1] See W. F. G. Swann, *Terr. Mag.*, vol. 20, pp. 30–43, 1915.

This neglects the ionization due to the β-rays and γ-rays in the ionization chamber; but such ionization is small in view of small range of action available, in the chamber, for these rays.

If we multiply the product of the quantities W and η, as defined in the specimen computation on page 400, by a factor h, to allow for the fact that some of the α-particles do not travel the whole of their range in the ionization chamber, we have

$$\eta Wh = \lambda_A N_A p + \lambda_C \overline{N}_C r + \lambda_C \overline{\overline{N}}_C r + \lambda_C N_C r \tag{13}$$

In so far as the fractional loss of ionization depends, in part, on the range of the α-particles, the quantity h theoretically depends upon the ratio of the amounts of ionization from the A and C products, and this ratio varies with the time. In practice, however, since the radium A decays to half its activity in about 3 minutes, practically the whole of the measurements depend upon the ionization by radium C. Thus, in the calculation of h, which will be explained later, the range has, as an approximation, been taken as that of the radium C particles. This does not, of course, imply that, at the end of a few minutes, the influence on the shape of the decay curve, of the radium A deposited, is lost, for the radium A produces radium B, and this, while it produces no ionization, slowly grows into radium C.

If we now substitute in (13) the values given by (8), (9), (11), (12), putting in the values of the constants λ_A, λ_B, and λ_C in the coefficients of the exponentials; and if we further note that the quantities n_A/W, n_B/W, and n_C/W represent respectively the quantities n_a, n_b, and n_c, *i. e.*, the numbers of atoms of radium A, radium B, and radium C in the atmosphere, we find

$$\eta = \eta_1 + \eta_2 + \eta_3 \tag{14}$$

where

$$h\eta_1 = n_a(1.92e^{-\lambda_A t} + 5.36e^{-\lambda_B t} + 4.98e^{-\lambda_C t}) \times 10^5 \tag{15}$$

$$h\eta_2 = n_b(4.76e^{-\lambda_B t} - 4.21e^{-\lambda_C t}) \times 10^5 \tag{16}$$

$$h\eta_3 = n_c(1.56)e^{-\lambda_C t} \times 10^5 \tag{17}$$

Theoretically, the values of n_a/h, n_b/h, and n_c/h can be obtained from 3 points on the experimental curve. Such a method of determining the constants is, however, somewhat laborious, and not very satisfactory in the present case. If, however, the curves for η_1 and η_2 are plotted with arbitrary values of n_a/h and n_b/h, it turns out that, for both curves, the slope is practically zero at $t = 1{,}320$ seconds. Thus, the whole of the slope of the experimental curve at this point is due to η_3, and consequently at $t = 1{,}320$ seconds we have, using (14) and (17),

$$\frac{d\eta}{dt} = -\frac{\lambda_c n_c}{h}(1.56)e^{-1320\lambda_c} \times 10^5$$

which serves to determine n_c/h, since λ_C is known. The curves may thus be simplified into curves involving only curves of the types η_1 and η_2, and the values of n_a/h and n_b/h may be more satisfactorily determined. When n_a has been obtained, the emanation content may immediately be deduced from equation (7).

The quantity h was obtained from the following considerations: Suppose Pds represents the number of α-particles which, coming from an area ds of the foil, are initially shot out within unit solid angle. The total ionization to be expected from these α-particles is $Prds$, if they traveled their full range in air. The ionization to be expected, under the same conditions, from all of the α-particles emitted from the element ds would consequently be

$$I_0 = 4\pi Prds \tag{18}$$

Now half of the α-particles never succeed in leaving the metal foil, since they are shot directly into it, and of the $2\pi Pds$ particles which do leave the foil, a number strike the wall again before completing their range.

Suppose that a rod of length x be imagined supported at one end on a universal joint at the element ds, so that the other end of the rod may be slid along the inner surface of the cylinder. Let ω be the solid angle subtended between the tangent plane to the cylinder at ds, and the cone traced out by the rod as it rotates around a normal to this plane, with its free end touching the inner wall of the cylinder. Then, knowing the radius of the cylinder, it will obviously be possible to graphically determine ω as a function of x. Again, if R is the range of the α-particle, the loss of ionization due to the annihilation of the portion of the path from x to R is a function of $(R-x)$ of the same form for α-particles from all types of substances.[1] The form of the function can be determined from the ionization curve for the α-particles. Calling this function $f(R-x)$, we thus see that it is possible to plot $f(R-x)$ as a function of x, and so of ω; and, as regards the α-particles emitted from the element ds, the total loss of ionization as a result of the above action is,

$$Pds\int_0^\Omega f(R-x)d\omega$$

where Ω is the value of ω for $x=R$. Thus

$$I=2\pi rPds-Pds\int_0^\Omega f(R-x)d\omega$$

and observing that $I/I_0=1/h$, we have, using (18),

$$\frac{1}{h}=\frac{1}{2}-\frac{1}{4\pi r}\int_0^\Omega f(R-x)d\omega \tag{19}$$

With the ionization chamber used it was found that the second member on the right-hand side of (19) constituted a correction of about 18 per cent on I.

In view of the large amount of labor involved in analyzing the curves, and of the fact that the amount of emanation when calculated was extremely small, it was considered sufficient to combine the curves for the separate days into groups of about 10. The mean curve for each group was then drawn and the corresponding amount of emanation was deduced according to the above scheme. For the purposes of a statement of the results, in a more detailed but less absolute manner, the values of the quantity η corresponding to the time 3 minutes after the termination of the deposit have also been shown in Tables 79–83, for each of the days on which observations were taken.

RADIOACTIVE CONTENT OF THE SEA-WATER.

Attempts were first made to estimate this quantity by evaporating to dryness about one liter of sea-water and testing the residue. The chief difficulty associated with this method lies in the absorption, by the residue itself, of a large amount of the α-ray radiation. Some observations have been made by this method, but it is now felt more satisfactory not to attempt any actual determination of the radioactive content of the sea-water aboard the vessel, but to forward the complete residues to Washington. Here they can be redissolved, and their radium content may then be determined by the charcoal method. Owing to the desirability of making all such determinations at one time, this work has been postponed until the completion of the *Carnegie's* fourth cruise. Thus, no data for the radium-emanation content of the sea-water are recorded in this report.

[1] Since, if the number of ions produced per unit length of path be plotted against the distance from the end of the range, the curve so obtained is the same for all substances.

METEOROLOGICAL OBSERVATIONS.

The meteorological elements are determined according to well-known methods, and no special mention of the procedure is necessary, further than to record that the relative humidity was obtained by means of a sling hygrometer, the atmospheric pressure by means of a mercurial barometer, and the temperature by an ordinary thermometer, with the exercise of the usual precautions. A barograph and a thermograph are also in use for the purpose of obtaining continuous records. The meteorological observations are recorded as shown on page 401, and on the same form is recorded also the summary of the atmospheric-electric observations for the day.

SPECIMENS OF OBSERVATIONS AND OF COMPUTATIONS.

EXPLANATORY REMARKS.

The forms are almost self-explanatory when read in conjunction with the account of the method of procedure as given on pages 377–396. The letter *d*, over many of the numbers, indicates that these numbers are recorded in scale divisions of the electroscope. Adjacent to such readings the corresponding values are recorded in volts when necessary.

Atmospheric-Electric Observations: Potential-Gradient

(Form 102)

Station: At sea *Lat:* 54°3 S *Long:* 326°8 E
Date: Jan. 15, 1916 *Com'd'r:* J. P. A. *Obs'r:* I. A. L.
Instrument: P. G. A. 2 *Watch:* 70

Watch Time	Electroscope Readings								$V=(V_1-A)$
	V_1 (1)				A (2)				
	Left	Right	Sum		Left	Right	Sum		
h *m*	*d*	*d*	*d*	*volts*	*d*	*d*	*d*	*volts*	*volts*
10 08	54	42	96	....	30	31	61	....	....
10 09	53	47	100	....	..	..	..	....	....
10 10	48	45	93	....	..	..	..	....	....
10 11	45	40	85	....	..	..	..	....	....
10 12	47	43	90	....	..	..	..	....	....
10 13	47	41	88	....	..	..	..	....	....
10 14	43	41	84	....	32	29	61	....	....
10 15	49	41	90	....	..	..	..	....	....
10 16	46	42	88	....	..	..	..	....	....
10 17	47	38	85	....	..	..	..	....	....
10 18	42	38	80	....	..	..	..	....	....
10 19	49	40	89	....	32	29	61	....	....
10 20	42	38	80	....	..	..	..	....	....
10 21	42	37	79	....	..	..	..	....	....
10 22	40	38	78	....	..	..	..	....	....
10 23	54	47	101	....	33	28	61	....	....
10 24	48	41	89	....	..	..	..	....	....
10 25	52	45	97	....	..	..	..	....	....
10 26	43	37	80	....	..	..	..	....	....
10 27	57	48	105	....	..	..	..	....	....
Means..................			89	126.6			61	82.5	44.1

Mean value $V=V_m=44.1$ volts.
Reduction factor to reduce to volts per meter, $B=2.8$.

Potential gradient, $X=BV_m=+123$ volts per meter.

Mean watch time $=10^h\ 17^m.5$; local mean time $=10^h\ 37^m$.
Remarks: Position of sails: Boom over port crutch, mainsail down.

	h *m*
Ship's Chronometer	12 23.8
Corr'n on G. M. T.	− 9.3
G. M. T.	12 14.5
Long.	2 12.7
L. M. T.	10 01.8
No. 70 reads......	9 42.7
Corr'n on L. M. T.	+19.1

[1] V_1 = potential of disk after fixed movement.
[2] A = auxiliary potential on electroscope; it is taken as positive when its sign is opposite to that of V.

In the observations of the potential-gradient, the positions of both fibers of the electroscope are recorded, and are designated in the form by "left" and "right," respectively. Space is provided for the conversion to volts of each of the readings so obtained. When, however, over the range used, the scale of the electroscope is sufficiently linear as regards potential variations, it is sufficient to deal, as in the example given, with the means of the scale differences, and convert these to potentials.

Atmospheric-Electric Observations: Ionic Content, Conductivity, and Specific Velocity[1]

(Form 101)

Station: At sea	*Lat:* 54°35 S	*Long:* 326°8 E
Date: Jan. 15, 1916	*Com'd'r:* J. P. A.	*Obs'r:* H. F. J.
Inst: I. C. 1 and C. A. 3	*Watch:* 106	

Ionic Content (ions per c. c.; sign +)

Meter	ΔM for change θ	W^{-1}		h m
d 2040 2135	95	94.8×10^{-7}	Began main obs'ns after first leak-test T_1 End main obs'ns before second leak-test T_2	10 03.0 10 10.0
2300 2385	85	106.0×10^{-7}	Mean watch time, T_m Local mean time	10 06.5 10 26
Mean $=W_m^{-1}$		100.4×10^{-7}		

$\theta=\overset{d}{47}-\overset{d}{49}=\overset{d}{-2.0}$

$\delta V=\overset{volts}{0.45}-\overset{volts}{0.05}=\overset{volts}{0.40}$

$\theta_1=\overset{d}{48.1}-\overset{d}{48.0}=\overset{d}{0.1}$

$\theta_2=47.4-47.3=0.1$

$\Delta t_1=\overset{h}{10}\ \overset{m}{01}\ \overset{s}{50}-\overset{h}{10}\ \overset{m}{00}\ \overset{s}{10}=\overset{s}{100}$

$\Delta t_2=10\ 13\ 20-10\ 11\ 40=100$

$\left.\begin{array}{l} t_1^{-1}=\dfrac{\theta_1}{\theta}(\Delta t_1)^{-1}=-0.5\times10^{-3} \\ t_2^{-1}=\dfrac{\theta_2}{\theta}(\Delta t_2)^{-1}=-0.5\times10^{-3} \end{array}\right\} t_m^{-1}=-0.5\times10^{-3}$

p = time in sec. for 1 c. c. air to flow through inst. $=7\times10^{-4}$ s.;

$w_m^{-1}=pt_m^{-1}=-3.5\times10^{-7}$

C = capacity of ion counter $=32.1$ cm.

n = No. of ions per c.c. $=\dfrac{C\delta V}{300e}(W_m^{-1}-w_m^{-1})=948$

Conductivity (sign +)

Watch time (h m s)	τ	τ^{-1}
10 03 50 05 50	120	8.33×10^{-3}
10 07 30 09 15	105	9.52×10^{-3}
Mean $=\tau_m^{-1}$		8.92×10^{-3}

	h m
Watch time, T_1	10 03.0
" " T_2	10 10.0
Mean, T_m	10 06.5
Correction on L.M.T.	+19
Local mean time	10 26

Φ_1 = initial reading of electroscope $=\overset{d}{45}$

$\theta=\overset{d}{45}-\overset{d}{40}=\overset{d}{5}$

$\delta V=\overset{volts}{104}-\overset{volts}{93}=\overset{volts}{11}$

$\theta_1=\overset{d}{43.2}-\overset{d}{43.0}=\overset{d}{0.2}$

$\theta_2=42.7-42.5=0.2$

$\Delta t_1=\overset{h}{10}\ \overset{m}{01}\ \overset{s}{40}-\overset{h}{10}\ \overset{m}{00}\ \overset{s}{00}=\overset{s}{100}$

$\Delta t_2=10\ 13\ 10-10\ 11\ 30=100$

$\left.\begin{array}{l} t_1^{-1}=0.4\times10^{-3} \\ t_2^{-1}=0.4\times10^{-3} \end{array}\right\} t_m^{-1}=0.4\times10^{-3}$

$A=\overset{d}{-}\ \overset{volts}{=0}$

$\dfrac{C_1}{C}=2.25$

$\Phi=\Phi_1-\dfrac{\theta}{2}=\overset{d}{42.5}$ $\qquad V_1=\overset{volts}{98.5}$

$V'=V_1-A=98.5$ volts

$\lambda=\dfrac{\delta V}{4\pi V'}\dfrac{C_1}{C_2}(\tau_m^{-1}-t_m^{-1})=1.70\times10^{-4}$

Specific velocity (sign +) $=v=\dfrac{\lambda}{300ne}=1.27$ cm. per second per volt per cm.

Definitions: θ = fiber movement in scale divisions; δV = value of θ in volts; W = total air-flow in c. c.; e = electronic charge $=4.8\times10^{-10}$ E.S.U.; C_1 = capacity whole apparatus; C_2 = capacity portion exposed to air-current; Φ = mean scale-reading during fall θ; V_1 = value of Φ in volts; V' = mean potential central conductor during fall θ; A = auxiliary potential applied to case of electroscope; it is taken as positive when its sign is opposite to that of V'; θ_1 and θ_2 = alterations in scale readings in the times Δt_1 and Δt_2, respectively, during the leakage tests at the beginning and end of the experiment; τ = time for fiber to pass over range θ.

[1] For an explanation of the formulæ see pages 384-389.

Atmospheric-Electric Observations: Penetrating Radiation

(Form 104)

Station: At sea
Date: Jan. 15, 1916
Instrument: P. R. A. 1

Lat: 54°.3 S
Com'd'r: J. P. A.
Watch: 70

Long: 326°.8 E
Obs'r: H. F. J.

Watch Time		τ	τ^{-1}	Remarks
h m s		s		d d d
11 39 15 11 42 30		195	5.13×10^{-3}	θ = 49.0 − 48.0 = 1.0 volts volts volts δV = 0.17 − 0.56 = 0.39
11 44 20 11 51 00		400	2.50×10^{-3}	
11 52 15 11 58 15		360	2.78×10^{-3}	Very rough sea
12 02 10 12 07 30		320	3.12×10^{-3}	
12 07 50 12 12 55		305	3.28×10^{-3}	
Means	11h 56m.1		3.36×10^{-3}	

12h 15m = local mean time
θ = fixed alteration in scale divisions
δV = fixed alteration in volts
C = capacity of system = 9.8 cm.
e = electronic charge = 4.8×10^{-10} E.S.U.
U = volume of apparatus = 21.6×10^{3} c.c.
R = number of pairs of ions produced per c. c. per second $= \frac{C\delta V\tau_m^{-1}}{300\,Ue} = 4.22$

	h m
Ship's Chronometer	12 23.8
Corr'n on G. M. T.	− 9.3
G. M. T.	12 14.5
Long.	2 12.7
L. M. T.	10 01.8
Watch 70 reads	9 42.7
Corr'n on L. M. T.	+19.1

Atmospheric-Electric Observations: Radioactive Content

(Form 103)

Station: At sea *Lat:* 54°.3 S *Long:* 326°.8 E *Obs'r:* H. F. J.
Date: Jan. 15, 1916 *Inst:* R. C. A. 4. *Com'd'r:* J. P. A.

Set number	1	2	3	4	5	6	7	8	9	10	11	12
Watch 70	h m s	m s	m s	m s	m s	h m s	m s	m s	m s	m s	m s	m s
For first scale-reading	11 17 05	23 15	30 15	38 25	48 50	12 01 15	14 30	29 15				
For scale changed by fixed amount θ	11 21 35	28 50	37 00	47 25	59 05	12 13 15	28 05	44 10				
τ = time taken in sec. for θ	270	335	405	540	615	720	815	895				
Collection of deposit	Watch time	ΔT		Meter reads	13	14	15	16	17	18	19	20
	h m	s		feet								
Began at T_1	10 44	1,800		11,500								
Ended at T_2	11 14			48,100								
Mean T_1 and $T_2 = T_m$	10 59	$\Delta M = 36{,}600$										
L. M. T.	11 18											

$\theta = 48 - 49 = -1.0$ (d d d) $\delta V = 0.35 - 0.11 = 0.24$ (volts volts volts)

θ_1 = scale alteration for leak test $= 48.1 - 48.1 = 0.0$ (d d d)

Δt_1 = time change for θ_1 $= 11\ 12\ 10 - 11\ 02\ 10 = 600$ (h m s h m s s)

$t_l^{-1} = \frac{\theta_1}{\theta}(\Delta t_1)^{-1}$ at beginning of experiment $= 0.0$

k = factor to reduce ΔM to c.c. = 5000.

W = air-flow in c.c. per second $= k\Delta M/\Delta T = 102\times10^3$

K = capacity of ionising chamber and electroscope = 12.0 cm.

e = electronic charge $= 4.8\times10^{-10}$ E.S.U.

Watch corr'n on local mean time: $+0^h\ 19^m.1$

Means corresponding to a single point of the decay curve

Sets number	1 to 1	2 to 2	3 to 3	4 to 4	5 to 5	6 to 6
	h m	h m	h m	h m	h m	h m
Chron. time	11 19.3	11 26.0	11 33.6	11 42.9	11 54.0	12 07.2
	s	s	s	s	s	s
Mean $\tau = \tau_m$	270	335	405	540	615	720
τ_m^{-1}	0.0037	0.0030	0.0025	0.0018	0.0016	0.0014
$(\tau_m^{-1} - t_l^{-1})$	0.0037	0.0030	0.0025	0.0018	0.0016	0.0014
$\eta = \frac{K\delta V}{300We}(\tau_m^{-1} - t_l^{-1})$	0.73	0.59	0.49	0.35	0.31	0.27

η = number of pairs of ions produced per second in the ionisation chamber, due to the active material which would be deposited in an air-flow of 1 c.c. per second.
η_0 = value η 3 minutes after end of collection of deposit = 0.76
Remarks:

In the above observations on the radioactive content of the atmosphere, the times at which the fiber crosses the fixed marks are recorded in columns 1–20. In exceptional cases, where a large amount of active material is collected, one can, in a short time, make several determinations of the quantity τ. In such cases it is possible to group the observations in columns 1–20 about certain mean times, so that several of the observations may have their share in the determination of each point of the curve actually drawn for η. For this purpose is employed the table headed "Means corresponding to a single point of the decay curve." In general, however, as in the example cited, the amount of active material collected is so small that it is not possible to adopt this scheme, and the intervals τ_m recorded are the same as the intervals τ.

Daily Summary of Atmospheric-Electric and Meteorological Observations

(Form 110)

Station: At sea	*Weather:* o	*Lat:* 54°3 S	*Long:* 326°8 E
Date: Jan. 15, 1916	*Course:* E ½ S	*Com'd'r:* J. P. A.	*Obs'rs:* H.F.J. and I.A.L.
Vessel: Carnegie	*Sea:* R	*Wind:* W by S, 6	*Roll or Heel:* 10° s. 10° p.

Summary of Atmospheric-Electric Observations[1]

Local Mean Time	Ions per c. c.		Conductivity		Specific Velocity	
	Positive n_+	Negative n_-	Positive λ_+	Negative λ_-	Positive v_+	Negative v_-
h m			E. S. U.	E. S. U.		
10 42	926	839	1.72×10^{-4}	1.47×10^{-4}	1.32	1.25

$n_+/n_- = 1.10$ Potential-gradient $X = +123$ volt/meter

$\lambda_+ + \lambda_- = 3.19\times10^{-4}$ E. S. U.

Air-earth current-density $= \dfrac{(\lambda_+ + \lambda_-)X}{3\times10^4} = 1.31\times10^{-6}$ E. S. U.

η_0 = value of η corresponding to time 3 minutes after completion of deposit[2] = 0.80

R = number of pairs of ions produced per c. c. per sec. = 4.22

Remarks:

Meteorological Summary

Local Mean Time	Thermometer readings			Relative Humidity	Pressure		Remarks
	Wet bulb	Dry bulb	Difference		Barom.	Att. Therm. C.	
h m	°	°	°	*per cent*	*mm.*	°	
11 09	3.0	4.0	1.0	85	740.1 741.2 739.4 740.3		Clouds: Cu-N, 10
				Mean	740.2	10.1	

[1] As pointed out on page 386, the mean values of the conductivity, ionic content, and specific velocity as here recorded are obtained on the basis of 3 sets of observations. In the example on page 398, however, only one set is shown.

[2] η = number of pairs of ions produced per second in the ionization chamber due to the active material which would be deposited in an air-flow of 1 c.c. per second.

TABLES OF RESULTS OF ATMOSPHERIC-ELECTRIC OBSERVATIONS ON CRUISE IV OF THE CARNEGIE.

EXPLANATORY REMARKS.

The following definitions will explain the meanings to be attached to the symbols at the heads of the tables:

P = atmospheric pressure in millimeters of mercury, corrected for zero error of barometer, temperature and latitude;

T = temperature, in degrees centigrade;

H = relative humidity, expressed as a percentage;

n_+ and n_- = respectively, the numbers of positive and negative ions per c.c.;

λ_+ and λ_- = unipolar conductivities in E.S.U.$\times 10^{-4}$, for positive and negative ions respectively;

v_+ and v_- = specific ionic velocities, in centimeters per second per volt per centimeter, for positive and negative ions respectively;

X = potential-gradient in volts per meter;

i = air-earth current density in E.S.U.$\times 10^{-7}$;

R = rate of production of pairs of ions per c.c. per second in a closed copper vessel of 27 liters capacity;

η_0 = number of pairs of ions produced per second, in the ionization chamber of the radioactive content apparatus, 3 minutes after the completion of the deposition, and corresponding to the active material which would be deposited in an air-flow of 1 c. c. per second; and

Q = radium-emanation content in curies$\times 10^{-12}$ per cubic meter. Values of Q less than 0.05 are recorded as 0.0. There is, of course, no proportionality between η_0 and Q, since the latter quantity involves the shapes of the experimental decay-curve.

The wind strengths are estimated on the Beaufort scale, and the weather indications according to the U. S. Weather Bureau's instructions for marine observers; the degree of cloudiness is indicated by the numbers 0 to 10.

The quantities under the heading Q have been obtained as explained on pages 393–396.

The decay curves for the sets of daily observations have been divided into groups of about 10, and the mean curve has been constructed for each group. These mean curves have then been used for the calculation of the corresponding values of Q. The braces under Q in the tables serve to indicate the periods to which correspond the values recorded between them.

On December 9, 1916, the *Carnegie* crossed the 180-degree meridian, which explains why this date appears twice in the tables.

TABLE 79.—*Atmospheric-Electric Results, Brooklyn to Colon, March 12–23, 1915.*

TABLE 80.—*Atmospheric-Electric Results, Balboa to Honolulu, April 13–May 20, 1915.*

TABLE 81.—*Atmospheric-Electric Results, Honolulu to Dutch Harbor, July 4–19, 1915.*

TABLE 82.—*Atmospheric-Electric Results, Dutch Harbor to Lyttelton, August 6–November 8, 1915.*

TABLE 83.—*Atmospheric-Electric Results, Lyttelton to South Georgia, and Return to Lyttelton, , 1915–March 31, 1916.*

DISCUSSION OF RESULTS OF CRUISE IV OF THE CARNEGIE.

The present compilation and discussion concerns itself primarily with the *Carnegie's* fourth cruise, but in so far as it includes a comparison of the data with those of former observers, it also serves as a general review of the present status of ocean atmospheric-electric observations.

The results for the daily determinations of the various elements are recorded in Tables 79–83, each table corresponding to one leg of the cruise. Apart from the observations on the diurnal variations, the measurements were always taken about the same time of day. The times recorded in the tables, which are local mean times, refer to the mean times during the determinations of the potential-gradient, conductivity, and ionic content, and the mean of these times for the whole cruise through March 1916 is $9^h.7$. The observations for the three elements referred to extended over a period of about three-quarters of an hour, the collection of the active material occurring during the last half hour of the period, or occasionally after the completion of the period. The measurement of the penetrating radiation followed immediately after the determination of the other elements, and it will be sufficient to look upon the determinations of this element as corresponding to a mean time one hour later than the times recorded in the tables. The observations for the diurnal variations are not shown in the tables, but will be discussed separately.

TABLE 84.—*Mean Values of Atmospheric-Electric Elements, Uncorrected for Dirunal Variation.*

The mean values of the quantities for each passage of the cruise are recorded in Table 84. The number of daily sets of observations involved in the determination of each mean is shown by the figures in parentheses, and in taking the means, each observation has been given equal weight. This was felt to be the fairest plan on the whole, since any attempt to weight the observations according to such conditions as the extent of the roll of the ship, for example, would implicitly involve attaching small weight to those observations corresponding to high strengths of wind. One set of computations was carried out for the first three rows in Table 84, weighting the observations according to the magnitude of the leak correction, as the determination of this correction seemed to be one of the main sources of error in the earlier sets of observations, although the correction was usually zero in the later observations. Only in the case of the voyage from Brooklyn to Colon, for which there were very few values, and where the means were largely controlled by one or two abnormal values, was any appreciable difference produced in the mean by this method of treatment.

Although, in view of the wide range of variation in the Atlantic-Ocean values of the conductivity and ionic content (see Table 79), no great weight is attached to these values as representative of normal conditions, it must be pointed out that the close agreement

of the values of v_+ and v_- with those obtained from the other passages of the cruise is evidence in favor of the reliability of the observations. It is further worthy of notice that, of the Atlantic-Ocean values recorded in Table 84, more than half were obtained in the land-locked Caribbean Sea, and the remainder just to the north of the West Indies. The results, therefore, while abnormal as Atlantic-Ocean values, are in harmony with those of the *Carnegie's* first and third cruises[1] in indicating low values for the ionic content and conductivity in the regions of transition between sea and land.

The desirability of basing the potential-gradient reduction factors on several determinations made under different conditions has already been emphasized on page 382. It is not often that one can find a location which, from a topographical point of view, is suitable, and on this account the reductions of the potential-gradients to absolute values have been made, thus far, on the basis of only one set of determinations of these factors, made in Colon Harbor, April 2, 1915. Thus the absolute values may be liable to some change as the accumulation of other determinations renders available more reliable values of the reduction factors. There is, however, no reason to believe that any considerable error attaches to the present factors.

On glancing at Table 84, it appears that, with the exception of the values of the conductivity and ionic content for the Atlantic Ocean, there is a much greater uniformity in the values of the various elements at different parts of the globe than is the case with land values. In support of this remark Tables 86–89 and Table 92 are given, showing a collection of land values obtained at different times and in different localities.

TABLE 85.—*Mean Values of Atmospheric-Electric Elements Corrected for Diurnal Variations.*

The more complete discussion of the diurnal variation over the ocean is taken up below, but it will be desirable here to anticipate, to some extent, the results for the purpose of reducing the observations to the daily mean values. This reduction has been made in Table 85, in which the quantities have been grouped into two sets—those corresponding to observations on the Pacific Ocean over the course Balboa-Honolulu-Dutch Harbor-Port Lyttelton, and those corresponding to the circumnavigation cruise in the sub-Antarctic Oceans between latitudes 50° and 60° south. For brevity, the former group is designated "Pacific" group, the latter "sub-Antarctic" group. Taking the case of the quantity n_+ for the purpose of illustrating the nature of the reduction, the mean value of all the times of determination for the "Pacific" values was $9^h.6$, the diurnal-variation observations themselves being omitted, and the mean value of n_- corresponding to the time $9^h.6$ was 845. The daily mean value of n_+[2] and the $9^h.6$ value as obtained from the diurnal-variation curve were respectively 810 and 840, so that multiplying 845 by 810/840 we obtain the daily mean value 811 recorded in Table 85.

This method of procedure depends on the assumption that the diurnal-variation curves are of the same form for the two portions of the cruise referred to, but it appeared on draw-

[1]See pages 367 and 375.

[2]The mean time throughout the Pacific and sub-Antarctic cruises, of all the determinations of n and X, omitting the diurnal-variation observations themselves, was $9^h.7$. It is of interest to point out that the values 838 and 128, which correspond to the mean $9^h.7$ values of n_+ and X for the whole cruise from Balboa onwards are comparatively near to the values 840 and 130 as obtained for this time from the diurnal-variation curves themselves.

ing the curves for these two sections, making use of such observations as were available, that this assumption was approximately justified. If an attempt were made to utilise the diurnal-variation curves for separate sections of the cruise, it would involve using curves in which the form was determined by observations on a comparatively small number of days, and such a procedure was not deemed desirable. In any case, the use of the mean diurnal-variation curve for the *whole* period involved is roughly justified for the correction of the *mean* values over that period. The diurnal-variation curves were obtained only for X, n_+, and R, and in the reductions made in Table 85, it has been assumed, as an approximation, that the form of the curve would be practically the same for n_+ as for n_-, λ_+, and λ_-. This assumption is, of course, only a rough approximation, for, among other things, it attributes no diurnal variation to n_+/n_-; but, as will readily be appreciated, it was not practicable to carry out complete diurnal-variation determination of all the elements.

In Table 85, the Atlantic-Ocean values from Brooklyn to Colon have been omitted because it is felt that the observations there were too few in number to render them characteristic of the whole ocean. Further, as already stated, the vessel was relatively near land when these observations were taken, so that from this standpoint also the data can hardly be considered as typical of ocean values. As a matter of fact, the inclusion of these values in the total means would hardly affect the result in view of their small number. It will be seen that there is no marked difference between the means for the Pacific and sub-Antarctic Oceans, and, indeed, the quantities representing the mean of the mean values for each of these regions are sensibly the same as the direct means for the whole set.

It is of interest to compare the values recorded in Table 85 with mean values obtained by other observers, on land and sea. Tables 86–92 contain a collection of values obtained by various observers in different localities. They have been drawn largely from pages 205–209, and page 255 of the article by E. von Schweidler and K. W. F. Kohlrausch on "Atmosphärische Elektrizität und des Magnetismus" (a section from vol. 3 of "Handbuch der Elektrizität und des Magnetismus," edited by L. Graetz). Some of the values recorded as land values were really measured over lakes, but except in the case of lakes of large area, the characteristics which control such measurements may reasonably be supposed to be those of the land.

COLLECTION OF LAND AND OCEAN VALUES OF ATMOSPHERIC-ELECTRIC ELEMENTS AS OBTAINED BY VARIOUS OBSERVERS IN DIFFERENT LOCALITIES.

TABLE 86.—*Ionic Content* (*Land Values*).

Observer	Place	Period	n_+	n_-	$\frac{n_+}{n_-}$	References
Lüdeling	Swinemünde	1904	583	458	1.27	Ergebnisse der Met. Beob. in Potsdam, 1902, p. 1, 1905.
Lüdeling	Potsdam	1904	770	625	1.23	Do.
Schweidler	Seewalchen (Up. Austria)	1904	937	792	1.18	Wien. Ber., vol. 113, p. 1433, 1904.
Schweidler	Mattsee (Salzburg)	1905	728	604	1.21	Wien. Ber., vol. 114, p. 1705, 1905.
Ebert	Munich	1905	1103	875	1.26	Phys. Zeit., vol. 6, p. 614, 1905.
Ebert	Jachenau (Up. Bavaria)	1905	1271	1625	0.78	Do.
Simpson	Karasjok (Lapland)	1904	792	687	1.15	Phil. Trans. R. Soc. A, vol. 205, p. 61, 1905.
Gockel	Freiburg (Switz.)	1904–05	708	521	1.36	Met. Zeit., vol. 23, p. 53 and 539, 1906; vol. 25, p. 9, 1908.
Wagner	Kalocsa (Hungary)	1909	1083	832	1.30	Wien. Ber., vol. 118, p. 1625, 1909.
Hess and von Sensel.	On the Danube, near Vienna.	1909	792	708	1.12	Wien. Ber., vol. 120, p. 139, 1911.
Dorno	Davos	1907–10	198	.....	.....	Licht und Luft im Hochgebirge, Braunschweig, 1911.
Daunderer	Aibling (Bavaria)	Summer 1906	1062	854	1.24	Phys. Zeit., vol. 10, p. 113, 1909.
Speranski	Moscow	1906–10	708	625	1.13	Met. Zeit., vol. 29, p. 557, 1912.
Kohlrausch	Seeham (Salzburg)	Summer 1912–13	646	625	1.03	Wien. Ber., vol. 123, 1914.
Berndt	Amazon	.....	375	354	1.06	Met. Zeit., vol. 31, p. 446, 1914.
Dobson	Kew	1911–12	438	321	1.37	Geophysical Memoirs No. 7, vol. 1, p. 167, 1914. The values given have, however, been corrected to correspond to the value 4.8×10^{-10}; E. S. U. for the electronic charge.
Dobson	Eskdalemuir	1911–12	358	183	1.96	Do.

TABLE 87.—*Conductivity* (*Land Values*).

Observer	Place	Period	λ_+ (E. S. U. $\times 10^{-4}$)	λ_-	$\lambda_+ + \lambda_-$	References
Czermak	Innsbruck	1901–03	1.4	1.3	2.7	Phys. Zeit., vol. 4, p. 271, 1903.
Gerdien	Göttingen	1906			2.3	Göttingen Nachr. Ges. Wiss., p. 84, 1907.
Schweidler	Mattsee (Salzburg)	Summer 1902	1.0	1.0	2.0	Wien. Ber., vol. 111, p. 1463, 1902.
Schweidler	Mattsee (Salzburg)	Summer 1903	1.6	1.6	3.2	Wien. Ber., vol. 112, p. 1501, 1903.
Schweidler	Seewalchen (Up. Austria)	Summer 1904	1.6	1.3	2.9	Wien. Ber., vol. 113, p. 1433, 1904.
Schweidler	Mattsee (Salzburg)	Summer 1905	1.4	1.5	2.9	Wien. Ber., vol. 114, p. 1705, 1905.
Schweidler	Ossiachersee (Carinthia)	Summer 1906	2.4	2.3	4.7	Wien. Ber., vol. 115, p. 1269, 1906.
Schweidler	St. Gilgen (Salzburg)	Summer 1907	1.8	1.5	3.3	Wien. Ber., vol. 118, p. 91, 1909.
Schweidler	Seeham (Salzburg)	Summer 1908	1.6	1.4	3.0	Do.
Schweidler	Seeham (Salzburg)	Summer 1910	1.7	1.6	3.3	Wien. Ber., vol. 119, p. 1839, 1910.
Schweidler	Seeham (Salzburg)	Summer 1911	1.6	1.6	3.2	Wien. Ber., vol. 121, p. 1297, 1912.
Schweidler	Seeham (Salzburg)	Summer 1912	1.4	1.4	2.8	Do.
Kähler	Potsdam	1909–10	0.4	0.4	0.8	Veröff. Kgl. Preuss. Met. Inst. 1910, No. 223.
Berndt	Argentina	1911	0.5	0.5	1.0	Phys. Zeit., vol. 12, p. 1125, 1911.
Dorno	Davos	1910	1.5	1.3	2.8	Licht und Luft im Hochgebirge, Braunschweig, 1911.
Ansel	Iceland	1910			3.0	Göttingen Nachr. Ges. Wiss., part 1, 1912.
Simpson	Simla (India)	1909			5.8	Phil. Mag. (6) vol. 19, p. 723, 1910.
Wilson	Peebles (Scotland)	1906–07			1.1	Proc. R. Soc. A, vol. 80, p. 546, 1908.
McOwan	Edinburgh	1909			0.4	Edinburgh Proc., vol. 30, p. 460, 1909–10.
Lutz	Munich	1909			0.4	Münch. Ber., p. 305, 1911.
Thaller	Gmunden (Up. Austria)	Summer 1909	0.7	0.7	1.4	Wien. Ber., vol. 122, p. 1817, 1913.
Thaller	Grünau (Up. Austria)	Summer 1913	1.4	1.5	2.9	Do.
Kohlrausch	Seeham (Salzburg)	Summer 1912	1.0	0.9	1.9	Wien. Ber., vol. 123, 1914.
Berndt	Amazon	1913–14	0.4	0.3	0.7	Met. Zeit., vol. 31, p. 446, 1914.

TABLE 88.—*Air-Earth Current-Density* (*Land Values*).

Observer	Place	Period	i (E.S.U. $\times 10^{-7}$)	References
Ebert	Locality of Munich	1901	5.1	Phys. Zeit., vol. 3, p. 338, 1902.
Wilson	Peebles (Scotland)	1906–07	6.6	Proc. R. Soc. A, vol. 80, p. 537, 1908.
Gerdien	Göttingen	1906	8.1	Göttingen Nachr. Ges. Wiss., p. 84, 1907.
Simpson	Simla (India)	1909	5.4	Phil. Mag. (6) vol. 19, p. 715, 1910.
Lutz	Munich	1909	3.0	Münch. Ber., p. 305, 1911.
Kähler	Potsdam	1909–11	7.1	Veröff. d. Kgl. Preuss. Met. Inst., No. 223, p. 30, 1910; Phys. Zeit., vol. 13, p. 216, 1912.
Carse and McOwan	Edinburgh	1909	4.2	Edinb. Proc., vol. 30, p. 460, 1910.
Ansel	Iceland	1910	9.0	Göttingen Nachr. Ges. Wiss., part 1, 1912.
Dorno	Davos	1910	5.1	Licht und Luft im Hochgebirge, 1911.
Schweidler	Seeham (Salzburg)	1912	8.3	Wien. Ber., vol. 122, p. 137, 1913.
Gockel	Freiburg (Switz.)	1913	9.5	Arch. scienc. phys. et nat., vol. 35 to 37.

TABLE 89.—*Specific Velocities* (*Land Values*).

Observer	Place	Period	v_+ $\left(\frac{\text{cm.}}{\text{sec.}} / \frac{\text{volt}}{\text{cm.}}\right)$	v_-	References
Gerdien	Göttingen	1903	1.36	1.63	Phys. Zeit., vol. 4, p. 632, 1903.
Mache and Schweidler	Seewalchen (Up. Austria)	1904	1.02	1.25	Phys. Zeit., vol. 6, p. 71, 1905.
Gockel	Freiburg (Switz.)	1907	$\left\{\begin{matrix}0.90\\1.20\end{matrix}\right.$	$\left.\begin{matrix}1.00\\1.30\end{matrix}\right\}$	Met. Zeit., vol. 25, p. 9, 1908.
Daunderer	Aibling (Bavaria)	1906	0.94	1.06	Phys. Zeit., vol. 10, p. 113, 1909.
Kohlrausch	Seeham (Salzburg)	1912–13	1.05	1.05	Do.

TABLE 90.—*Ionic Content (Ocean Values).*

Observer	Period	Sea or Ocean	n_+	n_-	$\frac{n_+}{n_-}$	References
Boltzmann	1905	Atlantic	812	562	1.44	Phys. Zeit., vol. 6, p. 132, 1905.
Linke	1906	Pacific	458	375	1.22	Göttingen Nachr. Ges. Wiss., 1906.
Eve	1907	Atlantic	687	562	1.22	Phil. Mag., vol. 13, p. 248, 1907.
Pacini	1906	Mediterranean	895	583	1.53	Nuov. Cim., vol. 15, p. 5, 1908.
Simpson and Wright	1910	Atlantic and Pacific	770	646	1.19	Proc. R. Soc. A, vol. 85, p. 175, 1911.
Berndt	1911	Atlantic	687	562	1.22	Phys. Zeit., vol. 12, p. 857, 1911.
Knoche	1912	Pacific	1000	1000	1.00	Phys. Zeit., vol. 13, p. 322, 1912.
Berndt	1913	Atlantic	583	417	1.40	Met. Zeit., vol. 30, p. 606, 1913.

TABLE 91.—*Conductivity (Ocean Values).*

Observer	Period	Sea or Ocean	λ_+ (E.S.U. $\times 10^{-4}$)	λ_-	References
Dike (Galilee)	1907–08	Pacific	1.60	1.43	Terr. Mag., vol. 13, p. 119, 1908.
Kohlrausch	1908	Atlantic	1.10	0.96	Sitz. d. Kgl. Ak. Wien., vol. 118, 2a, 1909.
Kidson (Carnegie)	1909–10	Atlantic	1.85	1.58	Terr. Mag., vol. 15, p. 83, 1910.
Kidson (Carnegie)	1910–11	Atlantic	1.62	1.29	Terr. Mag., vol. 19, pp. 162–170, 1914.
Kidson (Carnegie)	1911	Indian	2.31	1.97	Do.
Knoche	1911	Pacific	0.08	0.06	Phys. Zeit., vol. 13, p. 322, 1912.
Angenheister	1911	Red	1.00	0.85	Göttingen, Nachr. Ges. Wiss., 1914.
Angenheister	1911	Indian	1.62	1.32	Do.
Johnston (Carnegie)	1912	Pacific	1.39	1.10	Terr. Mag., vol. 19, pp. 162–170, 1914.
Hewlett (Carnegie)	1912–13	Pacific	1.40	1.13	Do.
Hewlett (Carnegie)	1913	Atlantic	1.91	1.58	Do.
Johnston (Carnegie)	1914	Atlantic	1.36	1.16	Terr. Mag., vol. 20, pp. 46–47, 1915.

POTENTIAL-GRADIENT.

Table 92 shows a collection of land results for the daily mean values of the potential-gradient corresponding to the whole year, as obtained in different localities. The mean of these values is 151 volts per meter, and the value 113 volts per meter recorded in Table 85, as the mean value for the Pacific and sub-Antarctic is of the same order of magnitude, though somewhat smaller. Only on three occasions during the whole cruise were negative potential-gradients observed. These negative values have been omitted in taking the means.

TABLE 92.—*Daily Mean Values of the Potential-Gradient Corresponding to the Whole Year (Land Values).**

Place	Potential-Gradient volt/m.
Kew	304
Kremsmünster	106
Triest	75
Karasjok	139
Munich	167
Potsdam	239
Batavia	120
Perpignan	55

*See E. von Schweidler and K. W. F. Kohlrausch: Article on *Atmosphärische Elektrizität* (a section from volume 3 of "Handbuch der Elektrizität und des Magnetismus"), p. 247; the value for Kew has, however, been altered in accordance with Phil. Trans. R. Soc. A, vol. 215, p. 140, 1915.

As regards ocean values obtained by other observers, these are not very numerous, for many who have made measurements of the potential-gradient on the sea have obtained only relative values. Johnston[1] obtained the value 93 volts per meter on the third cruise of the *Carnegie* in the North Atlantic Ocean in 1914; Simpson and Wright[2] obtained, in the South Atlantic and South Indian Oceans, values which appear to show a minimum of about 80 volts per meter in the neighborhood of 12 noon. Angenheister[3] found values ranging from 81 to 112 volts per meter in the Red Sea, and values ranging from 75 to 97 volts per meter in the Indian Ocean, while as early as 1907, Dike,[4] observing on the *Galilee*, in the Pacific Ocean, came to the conclusion that the potential-gradient was of the order of magnitude of 90 volts per meter.

[1]See page 373. [2]*Proc. R. Soc.* A, vol. 85, p. 175, 1911. [3]*Göttingen Nach. Ges. Wiss.*, 1914. [4]See page 364.

CONDUCTIVITY, IONIC CONTENT, AND AIR-EARTH CURRENT-DENSITY.

Turning now to the conductivity, ionic content, and air-earth current-density, the results recorded by other observers correspond frequently to all sorts of different times of the year and periods of the day, especially in the case of ocean values. Tables 86–89 show a collection of land values, while Tables 90 and 91 show a collection of ocean values. The means of these values are collected in Table 93, and the corresponding quantities from Table 85 have been added for comparison.

TABLE 93.—*Comparison of former Land and Ocean Values with the Ocean Values of Cruise IV.*

Nature of observations	n_+	n_-	$\frac{n_+}{n_-}$	λ_+ (E.S.U.×10⁻⁴)	λ_-	v_+ $\left(\frac{cm.}{sec.}/\frac{volt}{cm.}\right)$	v_-	i (E.S.U.×10⁻⁷)
Mean of land observations obtained by various observers	737	668	1.23	1.30	1.23	1.08	1.22	6.5
Mean of ocean values for the fourth cruise of the *Carnegie*	804	677	1.22	1.44	1.19	1.30	1.30	9.5
Mean of former ocean values obtained by various observers	736	588	1.28	1.44	1.20	......	......	....

The observations for v_+ and v_-, and for i, other than those of the present cruise, are too few in number to afford means for the table.

It will be seen that the present values of the ionic content are slightly higher than the means from other observers on the ocean and the mean of the land values. A glance at Tables 86 and 90 will, however, show that the means for other ocean observers and for land observations are means of relatively small numbers of widely differing quantities. On the other hand, as already stated, there is a remarkable constancy in the values of the ionic numbers as obtained throughout the present cruise.

The very close agreement will be noted between the values of λ_+ and λ_- for the *Carnegie's* fourth cruise and those of former observers on the ocean.

It is of interest to compare the present values of λ_+ and λ_- with the values obtained by former observers on the *Carnegie* and *Galilee*. We can do this only for the Pacific Ocean, since, as already stated, the fourth cruise values for the Atlantic Ocean are probably abnormal. The Pacific-Ocean values of λ_+ and λ_- as obtained on the former cruises of the *Carnegie* and *Galilee* are contained in Table 91. They vary somewhat, but the mean values $\lambda_+ = 1.46\times10^{-4}$ E.S.U., and $\lambda_- = 1.22\times10^{-4}$ E.S.U. are in remarkable agreement with the corresponding values 1.46×10^{-4} E.S.U. and 1.24×10^{-4} E.S.U. given in Table 85 as the mean Pacific-Ocean values for the *Carnegie's* fourth cruise.

Practically the only ocean value of the air-earth current-density with which to compare the present results is the value 7.7×10^{-7} E.S.U. obtained by Johnston[1] on the third cruise of the *Carnegie*. The latter value was, however, obtained in the North Atlantic Ocean.

The value of the air-earth current-density for the *Carnegie's* fourth cruise is considerably greater than the average land value; a rather curious circumstance with reference to the land values must, however, be noted. The mean of 8 land values of the potential-gradient as obtained from Table 92 is 151 volts per meter, and the mean of 24 land values of $\lambda_+ + \lambda_-$ as obtained from Table 87 is 2.4×10^{-4} E.S.U.; we should thus expect the mean air-earth current-density to lie in the neighborhood of $2.4\times10^{-4}\times1.51/300$, *i.e.*, 12×10^{-7} E.S.U. On the other hand, the mean of 11 land determinations obtained in different localities gives the value 6.5×10^{-7} E.S.U., recorded in Table 93. The discrepancy between 6.5 and 12 is so large, however, as to suggest that at any rate some of the means for λ_+, λ_-, X, and i as obtained from Tables 87, 88, and 92, are not truly representative of average

[1] See page 373.

land values. Some light is thrown on this disagreement when we observe that, on land, the values of the air-earth current-density have usually been measured with the Wilson electrometer,[1] while when the conductivity has been the main element sought, other types of apparatus have been more frequently used. There has been considerable diversity of opinion as to the proper method of using the Wilson electrometer, the uncertainty going so far as to have resulted in discussions of whether there should or should not be a factor of 2 in the formula used.[2]

SPECIFIC IONIC-VELOCITIES.

We have very few ocean values of the specific velocities with which to compare the present determinations. Practically the only data available are those of Knoche,[3] who found values in the neighborhood 0.05 cm. per second per volt per cm. in the Pacific Ocean; but it would seem that unless the conditions were exceptional in Knoche's experiments, this value must be subject to some doubt. The means of the land values as obtained from Table 89 are $v_+ = 1.08$ and $v_- = 1.22$. It is of interest to notice, however, that the present ocean values $v_+ = 1.30$ and $v_- = 1.30$ are in better agreement with laboratory values of the specific velocities deduced from determinations on dust-free air than are the land values measured in the open. Thus the values of v_+ and v_- obtained by Zeleny, for ions produced by Röntgen rays in moist air, are, at 14° C. and normal pressure, 1.37 and 1.51 cm. per second per volt per cm. respectively.[4] It is further of interest to notice that the ratio v_+/v_- is practically unity for the ocean values, whereas for the land values it is about 0.9.

It is very probable that the difference between the land and sea values for the specific velocities is attributable to the effect, on the measurements, of the so-called large ions formed by the union of small ions with dust nuclei. The effect of these large ions is to make the measured specific velocities of the small ions come out too small, and we should thus expect the measurements to lead to smaller values for the specific velocity on land, where there are many nuclei, than on the ocean, where there are few. In illustration of this point, it may be remarked that at Kew, which is in the vicinity of the smoky atmosphere of London, specific velocities are recorded as low as 0.5 cm. per second per volt per cm.[5] It would thus seem that the sea values are likely to be more accurately the representatives of the true specific velocities of the small ions than are the land values. When one considers the difficulties connected with ocean observations, the comparative constancy of the sea values as shown by Tables 84 and 85 is very encouraging, and adds weight to the accuracy of the determinations of both conductivity and ionic content, which are the elements from which v_+ and v_- are deduced.

PENETRATING RADIATION.

An examination of Tables 84 and 85 shows a remarkable constancy in the value of R, the number of pairs of ions produced per c. c. per second in a closed vessel, and the mean value 3.8 recorded in Table 85 is in general agreement with the results of Simpson and Wright,[6] who found values of R ranging from 4 to 6 in the Atlantic and Indian Oceans.

The values of R found over land are usually of the order of magnitude of 10 or more; and the discrepancy between the sea and the land values is readily accounted for by the part of the ionization which, in the case of the land values, is attributable to the γ-ray radiation from the radioactive material in the air and soil, and to the secondary β-ray radiation which this γ-ray radiation produces in the walls of the vessel. These sources of ionization are practically absent in the case of the ocean measurements, for there is very little radioactive material in the ocean or in the air over it.

[1] See C. T. R. Wilson, *Cambridge, Proc. Phil. Soc.*, vol. 13, pp. 363–382, 1906.
[2] See G. Dobson, *London, Proc. Phys. Soc.*, vol. 26, pp. 334–346, 1914.
[3] *Phys. Zeit.*, vol. 13, p. 325, 1912.
[4] *Phil. Trans. R. Soc.* A, vol. 195, p. 193, 1900.
[5] See E. H. Nichols, *Terr. Mag.*, vol. 21, p. 94, 1916.
[6] *Proc. R. Soc.* A, vol. 85, pp. 196–198, 1911.

RADIOACTIVE CONTENT OF THE AIR.

Former ocean measurements have concerned themselves with relative determinations, by the Elster-and-Geitel method, of the radioactive content over sea and land. The present method leads to an absolute determination of the amount of emanation in the atmosphere, and gives the value 3.3×10^{-12} curie per cubic meter for the Pacific-Ocean determinations, and 0.4×10^{-12} curie per cubic meter for the determinations in the sub-Antarctic Oceans.[1] The mean value for the whole cruise through March 1916, is 2.2×10^{-12} curie per cubic meter. Several absolute determinations of the radioactive content over land have resulted in a mean value of 88×10^{-12} curie per cubic meter,[2] so that the mean of the ocean values forms only 2.5 per cent of that found on land. The results of the present cruise are in general agreement with relative measurements over land and sea, in so far as one can attach any meaning to these relative measurements. Thus, in terms of the arbitrary unit defined by Elster and Geitel, Linke[3] found 2.4 and Knoche[4] 3.6 over the Pacific Ocean. The mean of these values is 3.0. As typical values for land stations we have the following: Wölfenbuttel[5] 19, Freiburg[6] 84, Karasjok[7] 93, Hochtal Arosa[8] (Switzerland) 91, Altjoch am Kochelsee[9] (upper Bavaria) 137. The mean of these activities is 85, of which the value for the Pacific Ocean forms about 3.5 per cent. The mean Pacific-Ocean value of Q for the *Carnegie's* fourth cruise forms 3.8 per cent of the land value, 88×10^{-12} curie per cubic meter, so that the comparison of the absolute values on land and sea is in good agreement with that of the corresponding relative values.

As will be seen from Table 85, the radioactive content for the sub-Antarctic oceans is much less than that for the Pacific Ocean. This result is in harmony with the experience of Simpson and Wright,[10] who call attention to the low value (3 Elster-and-Geitel units), for the radioactive content observed by them along latitude 40° S., between the Cape of Good Hope and Melbourne, as compared with the mean value (6 Elster-and-Geitel units) for their whole cruise from England to Melbourne. The present values for latitudes 50°–60° S. are, however, even smaller, in comparison with land values, than are those of Simpson and Wright for latitude 40° S., a point of considerable significance as suggesting a rapid diminution of the radioactive content with increase of southerly latitude.

The small value of the radioactive content over the ocean is, of course, in line with what might be expected when it is remembered that the radioactivity of the ocean air owes its origin almost entirely to the emanation transported by winds from the land. Over the small oceans, where the air has on the average passed more recently over land than is the case with the air over the large oceans, comparatively large values of the radioactive content are found. Thus, in the North Atlantic Ocean, Eve[11] found values of the radioactive content of the same order of magnitude as those found over land; Hewlett, on the *Carnegie's* second cruise, found an activity of 12[12] Elster-and-Geitel units, while Johnston on the third cruise found an activity of 23.[13]

As regards the effect of land on the radioactive content, Q, the results in Tables 80–83 are of considerable interest. The braces serve to divide the legs of the cruise into sections, the number tabulated representing, for the respective section, the mean value of the radium-emanation content in curies $\times 10^{-12}$ per cubic meter. Referring to Table 80, it will be observed that there was a regular diminution in the emanation content as the *Carnegie* passed from Balboa out into the Pacific Ocean en route for Honolulu. The voyage from Honolulu to

[1] In obtaining the mean value for the sub-Antarctic oceans, the values of Q for May 30 and 31, 1916, have been omitted, since these were obtained when the yacht was quite near the New Zealand coast and are obviously not representative of the general values obtained on the sub-Antarctic voyage.

[2] See E. von Schweidler and K. W. F. Kohlrausch, article on "*Atmosphärische Elektrizität*," p. 223 (a section from vol. 3 of "Handbuch der Elektrizität und des Magnetismus").

[3] *Göttingen Nach. Ges. Wiss.*, 1906.

[4] *Phys. Zeit.*, vol. 13, p. 112, 1912.

[5] See Elster and Geitel, *Phys. Zeit.*, vol. 4, p. 526, 1903.

[6] See Albert Gockel, *Phys. Zeit.*, vol. 5, p. 591, 1904.

[7] See G. C. Simpson, *Phil. Trans. R. Soc.* A, vol. 205, p. 61, 1905.

[8] See W. Saake, *Phys. Zeit.*, vol. 4, p. 626, 1903.

[9] See Elster and Geitel, *Phys. Zeit.*, vol. 5, p. 11, 1904.

[10] *Proc. R. Soc.* A, vol. 85, p. 186, 1911.

[11] *Terr. Mag.*, vol. 14, p. 25, 1909.

[12] See page 370. [13] See page 373.

Dutch Harbor (Table 81) took place for the most part in a region of the ocean far removed from land, and Q was small. For the voyage from Dutch Harbor to Port Lyttelton, Table 82 shows a decrease in Q as the land regions in the vicinity of Alaska were left behind, and in the parts of the cruise between 0° and 40° north latitude, where the *Carnegie* was very far from land, Q was very low. The value, however, increased again as the land regions formed by Australia and New Zealand were approached. Attention has already been called to the low values obtained for Q in the sub-Antarctic voyage. The values here were naturally variable, for the wind directions which are fruitful in bringing emanation to any point of the sub-Antarctic oceans are very limited in extent. This circumstance is emphasized by the fact that the ice-covered Antarctic Continent probably does not contribute appreciably to the emanation content of the winds coming from it.

Since a radium emanation content of 10^{-12} curie per cubic meter is sufficient to account for a rate of production of 0.021 ion per c. c. per second,[1] the average amount of radium emanation over the Pacific and sub-Antarctic Oceans, as determined by the results of the present cruise, is capable of accounting for the production of about 0.05 ion per c. c. per second.

CAUSES OF ATMOSPHERIC IONIZATION OVER THE OCEAN.

If we assume the well-known relation $q=\alpha n^2$, between n, the number of ions per c. c. of either sign, q the rate of production, and α the coefficient of recombination of ions, we can find the value of q necessary to account for any assigned value of n. The n which figures in the relation $q=\alpha n^2$ is somewhat greater than the values of either n_+ or n_- as measured, since the measured values are in part determined by the influence of the potential-gradient in altering the ionic distribution near the Earth's surface.[2] Thus, referring to Table 85, we see that according to the results of the present cruise a value of n at least as great as 800 must be accounted for. Further, there is in the atmosphere a class of ions, the so-called large ions, for which the specific velocity is only about 1/3000 of that of the small ions. These large ions are not measured by the ion counter, but the fact of their existence increases the rate of production of ions which it is necessary to postulate in order to account for atmospheric ionization. In order to account for the 800 small ions alone, we find, taking $\alpha=2.5\times10^{-6}$, that q must have a value equal to 1.6. Hence the radioactive material in the air over the great oceans is only sufficient to provide for about 3 per cent of the rate of production of ions necessary to account for the presence of the small ions alone. It is true that the uncertainties inherent in the method of determining the emanation content from the active deposit are such as to give a value which is too low, but after making all allowances for such considerations, we can not but conclude that the radioactive content over the large oceans is too small to play an important part in controlling the ionization of the atmosphere there. A similar remark applies to the radium emanation contained in the sea-water, which is likewise known to be excessively small, so that there remains, for the explanation of the bulk of the atmospheric ionization over the ocean, only that source, whatever it is, which is responsible for the formation of ions in a closed vessel.

As already stated, the results of the *Carnegie's* fourth cruise indicate a value 3.8 for the rate of production of pairs of ions per c. c. in a closed vessel. If we could assume all of the ions produced in a closed vessel over the sea to have their origin in causes other than the vessel itself, we should be provided with a source of ionization more than sufficient to account for the existence of the small ions; but the question as to how far the ionization produced in a closed vessel of this kind is really the result of actions other than that of radioactive impurities in the vessel is still to some extent an open one.

[1]For the theoretical basis underlying this calculation see E. von Schweidler and K. W. F. Kohlrausch, article on "*Atmosphärische Elektrizität*," p. 234 (a section from vol. 3 of "Handbuch der Elektrizität und des Magnetismus").

[2]See E. von Schweidler, *Wien. Ber.*, vol. 117, p. 653, 1908; also W. F. G. Swann, *Terr. Mag.*, vol. 18, p. 163, 1913.

Perhaps one of the chief difficulties resulting from a comparison of the ionization over the land and ocean arises from the fact that if we assume, as we must do, a sufficiently large value for the ionization caused by the penetrating radiation to account for the ionization over the ocean, *i. e.*, a rate of formation of 1.6 pairs of ions per c. c. per second, it would seem that we must consider this cause to be active over land also. Thus, the rate of production of pairs of ions which can be accounted for on land is at least 1.6 plus the rate of production which can be accounted for by the radioactive materials in the soil and atmosphere on land. The latter contribution amounts to 4.5 according to the estimates of Eve,[1] hence the value of q which can be accounted for on land is at least about 6, and this is much more than is necessary to account for the observed number of small ions, the latter being no greater than the value found at sea. It would seem that the explanation of this difficulty must be sought in the slowly moving ions, which, though they contribute very little to the conductivity, nevertheless have to be maintained, since they are continually suffering recombinations. The total number of ions, small and large, over the ocean must be supposed to be smaller than that over land, but the greater purity of the air over the ocean will result in the *fraction* of the ions which exist there as small ions being greater than the corresponding fraction over land. The practical equality of the measured numbers of small ions over land and sea drives us to the conclusion that, as far as this fact is concerned, the decrease in the total ionization over the sea is just compensated by the greater fraction of the ions which there function as small ions. Thus, for example, if we were to assume that there are no slowly moving ions over the sea, we should have $q=1.6$ as the total ionization over the sea. Hence, total ionization over land $=1.6+4.5=6.1$. Thus, if n_s and n_l refer to the total numbers of small ions per c. c. over sea and land, respectively, N to the number of large ions per c. c. over the land, and if α is the same for both classes of ions,

$$\frac{N+n_l}{n_s}=\left(\frac{6.1}{1.6}\right)^{\frac{1}{2}}=\text{about } 2$$

Hence, since $n_l=n_s$ approximately, we should on this basis find $N=n_l$, *i e.*, the number of small ions per c. c. on the land would be about equal to the number of large ions. If the ions over the sea are not entirely of the quickly moving class, an argument of this type would lead to the conclusion that the number of large ions over the land is greater than the number of small ions.

It will thus be gathered from the foregoing remarks that the two outstanding problems which are of primary importance for the satisfactory clarification of our ideas on the ionization over the land and sea are, (1) the problem of determining how much of the ionization produced in a closed vessel is to be attributed to causes other than the vessel itself, and (2) the problem of determining, over land and sea, the average number of slowly moving ions per c. c.

Although the radium emanation over the great oceans is insufficient to contribute markedly to the ionization there, its effect over a small ocean like the Atlantic is not insignificant. In this connection a point of some interest shows itself when we compare the average values of the conductivities over the Atlantic and Pacific Oceans. Taking the average of the values in Table 91 for the Atlantic Ocean, we find $\lambda_+=1.57\times10^{-4}$ E.S.U., and $\lambda_-=1.31\times10^{-4}$ E.S.U. The mean of these values is 1.44×10^{-4} E.S.U. Taking the average values for the Pacific Ocean as obtained by utilizing the values in Table 85 and the corresponding values in Table 91, the very low values 0.08×10^{-4} E.S.U. being, however, omitted, we obtain $\lambda_+=1.46\times10^{-4}$ E.S.U., and $\lambda_-=1.22\times10^{-4}$ E.S.U. The mean of these values is 1.34×10^{-4} E.S.U. Writing λ_a and λ_p for the mean unipolar conductivities over the Atlantic and Pacific Oceans respectively, we thus have $\lambda_a/\lambda_p=1.44/1.34=1.07$.

[1]*Phil. Mag.*, S. 6., vol. 21, p. 34, 1911. Eve gives the value 4.35 instead of 4.5. The slight difference is to be accounted for by the fact that Eve took 80×10^{-12} curie per cubic meter as the normal radium-emanation content of the atmosphere, whereas the value 88×10^{-12} curie per cubic meter has been adopted in this report.

Now, in so far as the conductivity is proportional to the ionic density, and the latter is proportional to the square root of the rate of production of pairs of ions, we should expect that if q is the value of the latter quantity for the Pacific Ocean, and $q+\delta q$ the value for the Atlantic Ocean,

$$\left(\frac{q+\delta q}{q}\right)^{\frac{1}{2}}=1.07$$

or approximately $\delta q/q=0.14$.

Taking the value $q=1.6$ found on page 414, for the great oceans, as the value for the Pacific Ocean, we thus find $\delta q=0.22$. As already stated on page 413, the mean value of the activity, expressed in Elster-and-Geitel units, for several land stations is 85, so that if this be taken as corresponding to the mean emanation content, 88×10^{-12} curie per cubic meter, for the land,[1] we find that 1 Elster-and-Geitel unit corresponds to 1.0×10^{-12} curie of emanation per cubic meter, and consequently, according to page 414, to a rate of production of 0.021 ion per c. c. per second.[2] In order to account for the above value 0.22 for δq, it would consequently be necessary to assume, over the Atlantic Ocean, a radioactive content which was in excess of that over the Pacific Ocean by about 10 Elster-and-Geitel units. Taking the mean value for the Pacific Ocean as 3 Elster-and-Geitel units,[3] we should, on these lines, expect 13 Elster-and-Geitel units over the Atlantic Ocean, and this is just about the order of magnitude of the radium-emanation content found there. Thus Hewlett found 12 and Johnston 23 Elster-and-Geitel units respectively, in the north Atlantic Ocean, on the *Carnegie's* second and third cruises; the mean of these values is 18.

It is noticeable that the slight difference between the average values recorded in Table 85 for the corresponding ionic contents and conductivities in the Pacific and sub-Antarctic oceans is in the right direction to be accounted for by the difference in the emanation content. The mean of the values of n_+ and n_-, recorded in Table 85 for the Pacific Ocean, is 752, and the corresponding value for the sub-Antartic oceans is 722. If q is again taken for the rate of production of pairs of ions per c.c. in the Pacific Ocean, and if $q-\delta q$ is the corresponding value for the sub-Antarctic oceans, we readily find, on the line of the argument given above,

$$\delta q=0.08q$$

so that taking $q=1.6$ as before, $\delta q=0.13$. This corresponds in radium-emanation content to $(0.13/0.021)\times10^{-12}=6\times10^{-12}$ curie per cubic meter. The difference between the Pacific and sub-Antarctic emanation contents amounts, according to Table 85, to 2.9×10^{-12} curie per cubic meter, and is thus of the right order of magnitude to account for the differences in the corresponding ionic contents. An exact numerical agreement can not, of course, be expected.

DIURNAL VARIATION.

As already stated, diurnal-variation measurements were made for the quantities X, n_+, and R, but it was naturally not practicable to make complete diurnal-variation observations very often. In so far as a diurnal-variation curve may only be expected to approximate to a definite and characteristic form when the results of many sets of observations are combined, it was considered best to combine, into one curve, for any element, all of the corresponding diurnal-variation observations throughout the cruise. A curve obtained in this way consequently corresponds to the mean diurnal-variation curve throughout the period of the cruise. Although the observations here discussed extended over about

[1]See page 413.

[2]Kurz has made a direct comparison of the Elster-and-Geitel unit with the corresponding amount of ionisation to be expected. His data have, at the hands of Kohlrausch and others, suffered various corrections which have changed the original result by 260 per cent of its value, and the corrected value gives the rate of production of pairs of ions per c.c., corresponding to 1 Elster-and-Geitel unit as 0.029. (See K. Kurz, *Abh. Ak. Wiss. Math.-phys. Kl.*, No. 1, vol. 25, p. 44, Munich, 1909; also K. W. F. Kohlrausch, *Phys. Zeit.*, vol. 13, p. 1193, 1912).

[3]See page 413.

one year, it is hardly possible to look upon the curves as comparable with mean diurnal-variation curves for the year, as obtained at one station, for the present observations correspond to all sorts of different latitudes.

The curves for X, n_+, and R are shown in Figure 26. It naturally turned out that there were many occasions on which observations were started and later in the day it was found necessary to discontinue them as a result of weather conditions. All of the observations have, however, been used in drawing the curves, so that the parts of the curves corresponding to the night depend upon fewer observations than those for the day. Each point on the curves is the representative of observations on a large number of days, and the number of days for the individual points are recorded against them. It is interesting to observe that the parts of the curves determined by points representative of the observa-

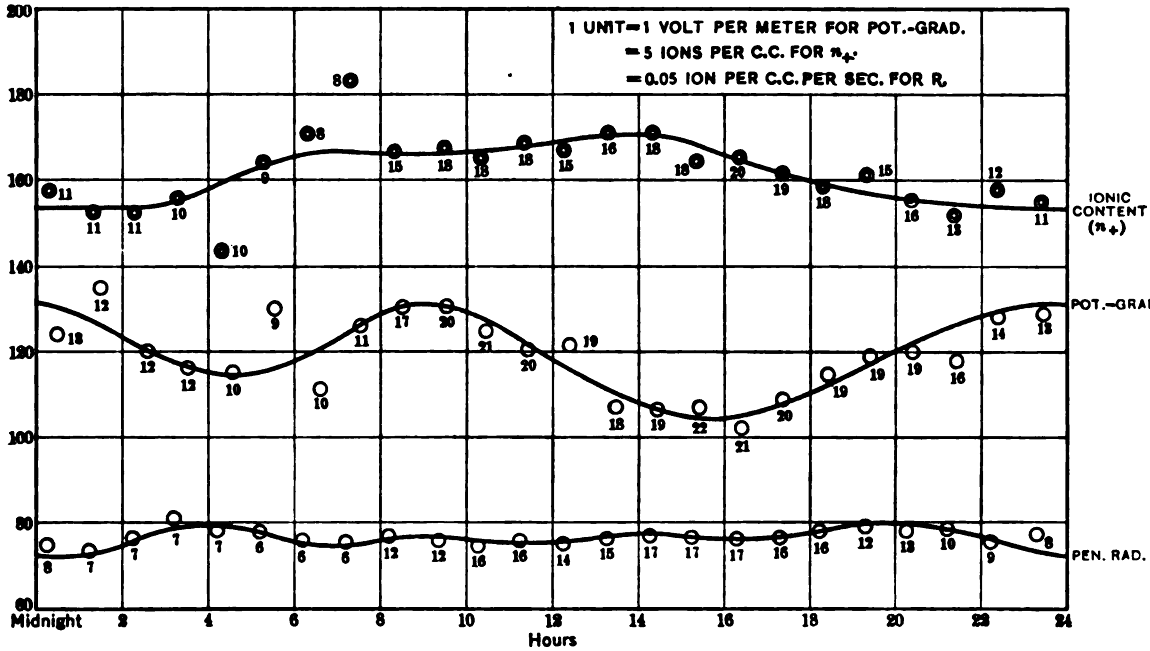


FIG. 26.—Ocean Diurnal-Variation Curves for Ionic Content, Potential-Gradient, and Penetrating Radiation.

tions on many days are much more definite in form than the parts determined by points corresponding to few observations, a result, of course, to be expected. Happily the doubtful parts of the curves are of sufficiently small extent to render it possible to draw them in with reasonable certainty by noting that, except for the slow progression of the annual variation, the curves must repeat themselves with a period of 24 hours. The curves for X and n_+ show definite diurnal variations, but the curve for R does not indicate any such tendency, and this point is emphasized by the fact that the portions of the curve which are fixed by the largest numbers of observations are just those which approximate most closely to the representation of R as independent of the time of day. This result, which is in harmony with the observations of Simpson and Wright in the Atlantic and Indian Oceans,[1] is not necessarily inconsistent with the results of those observers who, on land, have found diurnal variations in R, since, as already remarked, a large portion of R as measured on land is determined by the radioactive material in the soil and atmosphere.

Turning now to the potential-gradient curve, it is interesting to compare this curve with the mean diurnal-variation curves for the year for several land stations. This is done in Figure 27. It will be observed that the chief feature which characterizes the ocean

[1] Proc. R. Soc. A, vol. 85, p. 199, 1911.

curve is the fact that the early morning minimum is not so sharp as is usually the case with the land observations. When allowance is made for the difference in the absolute values of the potential-gradient, the land curve to which the ocean curve most closely corresponds is that for Potsdam. The relation comes out strongly when the Fourier amplitudes of the different harmonics are considered. If the potential-gradient be expressed in the usual form $X = a_0 + a_1 \sin(\varphi_1 + x) + a_2 \sin(\varphi_2 + 2x) + \ . \ . \ .$ etc., where the a's are amplitudes and the φ's phase angles, Table 94 gives for the first 3 Fourier "waves" the values of the a's and φ's for the curves plotted in Figure 27.

TABLE 94.—*Amplitudes and Phase Angles for Diurnal-Variation Curve of the Potential-Gradient.*

Place	a_0	a_1	a_2	a_3	φ_1	φ_2	φ_3	$\frac{a_1}{a_2}$	Remarks
					°	°	°		
Ocean values (Cruise IV)	119	6.8	9.3	2.5	218	147	230	0.73	*According to a more recent determination of the reduction factor for the apparatus at Kew (see *Phil. Trans. Roy. Soc.* A, vol. 215, p. 140, 1915), the Kew amplitudes should all be corrected by a constant factor. But since here we are only interested in the relative values of the amplitudes this correction has been omitted in this table, and in the corresponding curve for Kew in Fig. 27.
Potsdam	239	17	26	5	199	174	101	0.65	
Kew*	159	8	25	4	165	187	40	0.34	
Munich	167	39	35	4	250	190	76	1.11	
Kremsmünster	106	26	14	.....	231	186	.....	1.76	
Triest	75	42	5	.....	236	155	.....	8.67	
Samoa	37	21	2	3	220	271	349	11.40	

It will thus be seen that the curve for the ocean values partakes of the properties of the curves for Potsdam and Kew in showing, for the 12-hour "wave," an amplitude which is greater than that for the 24-hour "wave." A similar result was obtained by Simpson and Wright[1] in their observations over the Atlantic and Indian Oceans. The preponderance of the 12-hour term over the ocean is of special interest when it is recalled that over land the amplitude of this term appears to diminish very rapidly with altitude. Thus the ratio a_1/a_2 is very much larger at the top of the Eiffel tower than at a point on a level with the base. It has been customary to attribute the 12-hour term to dust carried up by convection currents during the hotter part of the day, but the preponderance of this term in ocean observations, where the air is very pure, would appear to cast some doubt on such an explanation, a point to which Simpson and Wright have also called attention.

The diurnal-variation curve of the ionic content shows a flat maximum extending over about 8 hours from 6 a. m. to 2 p. m., and a minimum about midnight, the amplitudes and phase angles of the first 3 Fourier "waves" being $a_0 = 810$, $a_1 = 41.8$, $a_2 = 3.3$, $a_3 = 8.2$, $\varphi_1 = 278°$, $\varphi_2 = 90°$, $\varphi_3 = 156°$. The diurnal range forms, in the case of the ionic content, only about 10 per cent of the whole. If this were all attributable to a change in the rate of production of ions, we should expect a diurnal range of about 20 per cent in the latter quantity; but we have seen that the observations give no evidence of any appreciable diurnal variation in R. Since the value of X controls, to some extent, the values of the ionic densities near the Earth's surface,[2] we may expect a diurnal variation in X to be accompanied by a diurnal variation in n_+; increase of X should be accompanied by decrease of n_+. On referring to Figure 26, we indeed find that the midnight maximum for X corresponds to a minimum for n_+, and although the early morning maximum of X is not accompanied by a distinct minimum of n_+, there is an indication of a tendency in this direction. There is, however, a further cause which contributes to the diurnal variation of the ionic content, for α, the rate of recombination of the ions, is known to decrease with increase of temperature, the decrease amounting, according to Erikson,[3] to about 1 per cent per degree at ordinary temperatures. The diurnal variation of the temperature, as

[1] *Proc. R. Soc.* A, vol. 85, p. 181, 1911.
[2] See E. von Schweidler, *Wien. Ber.*, vol. 117, p. 653, 1908; also W. F. G. Swann, *Terr. Mag.*, vol. 18, p. 163, 1913.
[3] *Phil. Mag.*, vol. 18, pp. 328–366, 1909.

indicated by the thermograph records, shows a maximum about the same time as the maximum in the curve for n_+, which fact is in harmony with the above view. The average daily range in temperature is about 5° C., and this corresponds to a range of about 5 per cent in α and consequently to about 2.5 per cent in n_+. Apart, however, from these considerations with regard to the variation of α, Simpson, in his experiments at Karasjok,[1] found, as an experimental fact, that the ionic content increased by about 35 per cent for 20 degrees increase in temperature. Such a change, which is considerably larger than that calculated from the change in α to be anticipated from laboratory experiments, is in itself almost sufficient to account for the present diurnal variation in n_+ as a pure result of the diurnal variation in temperature.

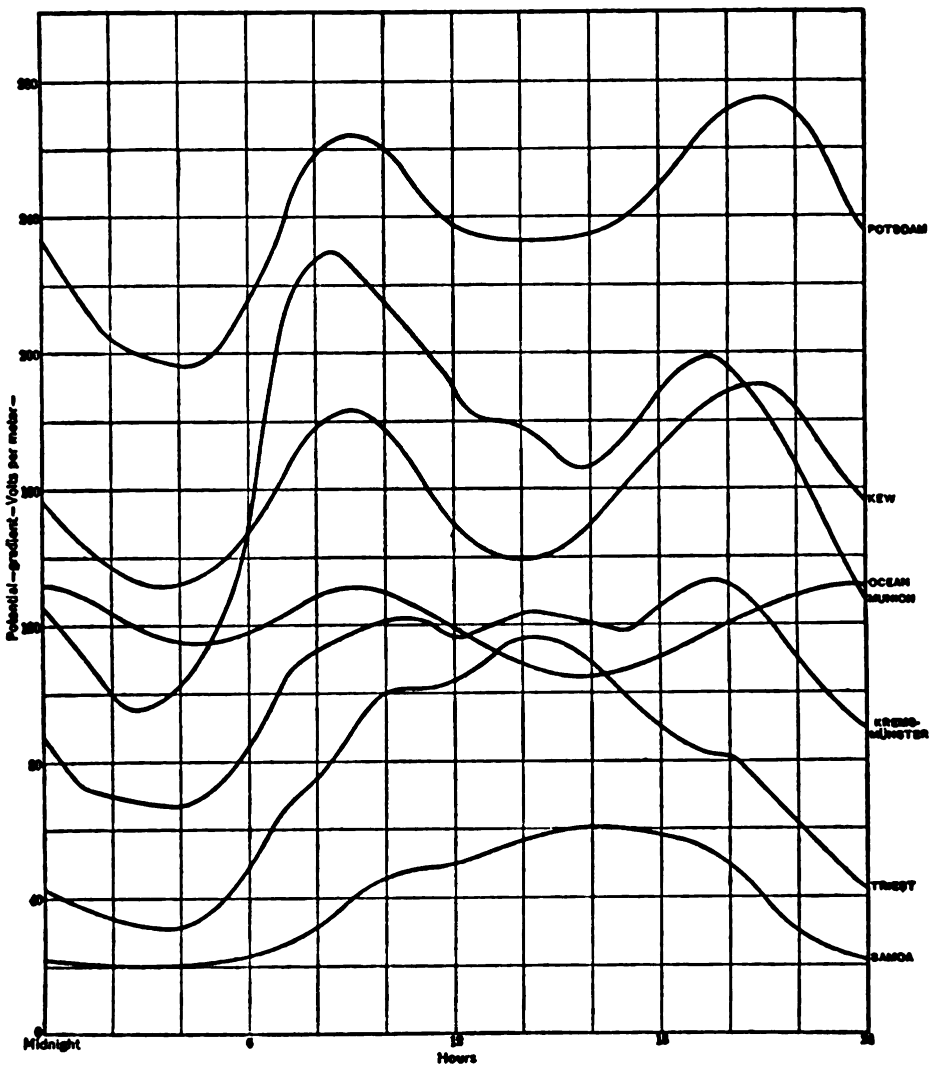


FIG. 27.—Comparison of the Potential-Gradient Diurnal-Variation Curve for the Ocean with Those for Various Land Stations.

The diurnal variation of the ionic content on land is influenced much by the local conditions. Gockel,[2] from measurements made at Freiburg, finds a maximum for n_+ at 2 p. m. in winter and at 4 p. m. in the summer. These results are in general agreement with those of the present cruise, except that they give the maximum somewhat later, a

[1] *Phil Trans. R. Soc.* A, vol. 205, p. 79, 1905. [2] *Met. Zeit.*, vol. 23, p. 53, 1906.

result which, however, would be expected if the diurnal variation were largely controlled by the temperature.

There are hardly any other ocean results with which to compare the present observations on the diurnal variation. Simpson and Wright,[1] on the basis of certain ocean observations made within 40° of the equator, came to the conclusion that the potential-gradient has its chief minimum soon after midday, a result in harmony with those of the present cruise, as will be seen on reference to Figure 26. Table 95 shows values obtained by G. Berndt[2] in the Atlantic Ocean in 1913. The potential-gradient results are here only relative, and X represents the means of the potential-gradient observations on all days, while X' represents the mean values as obtained on days labeled as normal from an atmospheric-electric standpoint, and in which negative values of the potential-gradient are omitted. These observations, as far as they go, are in agreement with the present results on the diurnal variation, at any rate in the cases of X' and the ionic content.

TABLE 95.—*Berndt's Results on the Daily Variation of Ionic Content and Potential-Gradient Over the Atlantic Ocean.*

Time	n_+	n_-	X	X'
8 a. m.	731	568	52	58
2 p. m.	772	640	54	51
8 p. m.	628	561	55	58

ANNUAL VARIATION.

In considering the type of annual variation to be expected from observations such as those at present under discussion, one has to remember that it is the season, rather than the time of the year, which controls the phenomena, so that it would not be reasonable to plot the quantities against the time without due regard to the variation with latitude. Thus, for example, account must be taken of the fact that the seasons are reversed in the southern hemisphere. However, since the circumnavigation voyage in the sub-Antarctic Oceans corresponds roughly to a constant latitude, it enables us to seek evidence on the annual variation over the period of duration of this voyage (about four months). To this end the 10^h2 values have been meaned for each of the four months, and the results plotted against the corresponding mid-times for the months.[3] The results are shown in Figure 28. Remembering that the seasons are reversed in the latitudes in question, we should, by analogy with the results for land values, expect a minimum of the potential-gradient in January. As a matter of fact, a maximum appears here, but this is followed so soon by a minimum that it is difficult to draw any conclusions as to the normal type of variation, and, indeed, it is probable that the mean of the observations over several years would be necessary to satisfactorily settle the question of the annual variation. In the case of the ionic numbers, conductivities, and air-earth current-densities, the curves suggest more definite conclusions and indicate distinct minima in January. The land observations in the northern hemisphere give minima for the ionic content and conductivity in the late winter months, and maxima in the late summer and autumn. In view of the reversal of the seasons in the southern hemisphere the results of the ocean observations are, therefore, somewhat surprising. However, it is difficult to form a proper opinion of the general curve of the annual variation from observations extending over four months, and it is possible that the minima which the present observations indicate for January are only depressions in the main maxima of the curves.

[1] *Proc. R. Soc.* A, vol. 85, p. 181, 1911.
[2] *Met. Zeit.*, vol. 30, p. 606, 1913.
[3] In the cases where there were no observations for certain periods of a month the time used is the mean time corresponding to the observations secured.

The quantity R shows a faint indication of a minimum in February, but the changes in R are so small that it is undesirable to discuss their origin in detail.

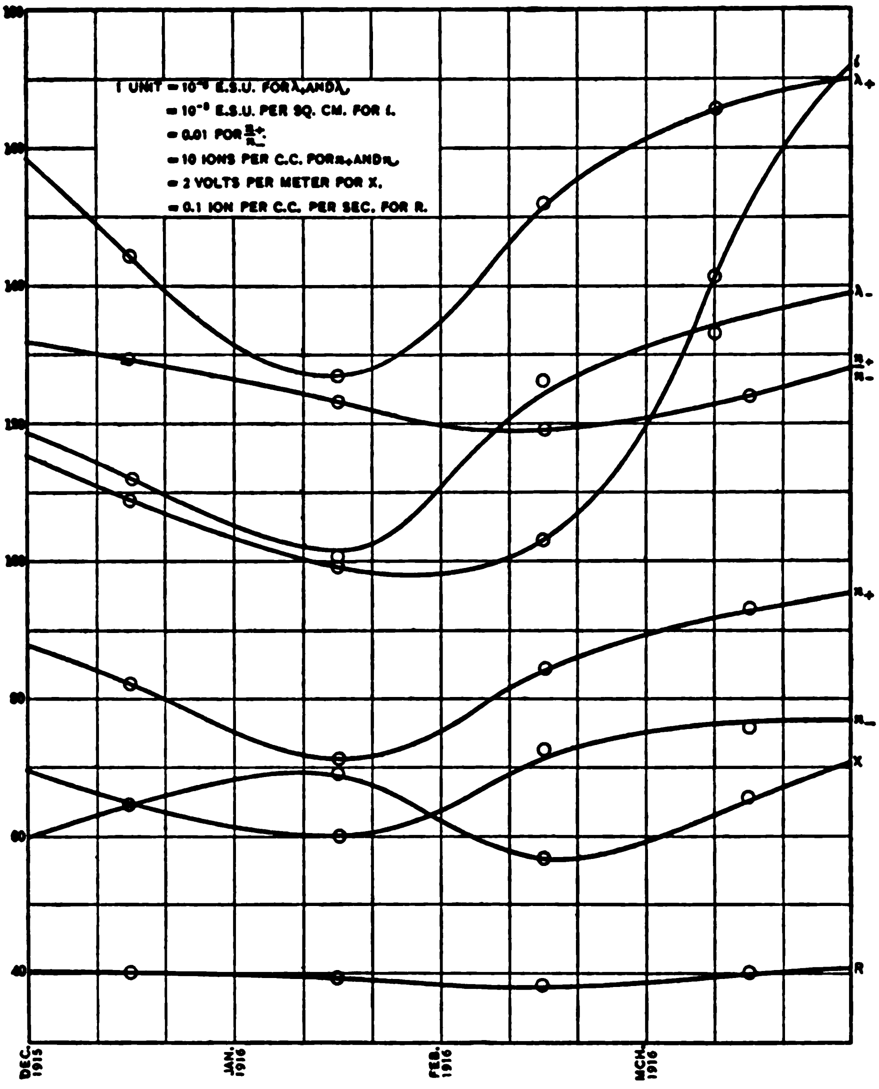


FIG. 28.—Variation of Atmospheric-Electric Elements during a Period of Four Months on the Sub-Antarctic Voyage.

Atmospheric-electric observations made aboard a vessel are manifestly not of a type well suited to the elucidation of annual variations in the elements, since the geographic location of the vessel alters continually. It is probable that ocean data on the annual variation, and indeed on the diurnal variation, could be most advantageously secured from observatories erected on small islands located in mid-ocean. In order that the results obtained may be free from local influence, the islands should be as free as possible from foliage. There are, however, very obvious practical difficulties involved in an attempt to carry on scientific work on an island whose chief characteristics are that it is barren and located in mid-ocean.

SUMMARY OF CONCLUSIONS.

A general discussion of the observations leads to the following general conclusions:

(1) The potential-gradient over the ocean has, according to the present observations, an average daily mean value of 113 volts per meter. It has a distinct diurnal variation with minima about 5 a. m., and 3 p. m., and maxima about midnight and 9 a. m., the 12-hour Fourier "wave" being more prominent than the 24-hour "wave."

(2) The average values, for the whole cruise through March 1916, of conductivities and ionic contents for positive and negative ions are, $\lambda_+ = 1.44\times10^{-4}$, $\lambda_- = 1.19\times10^{-4}$ E.S.U., $n_+ = 804$, and $n_- = 677$, and the mean value of n_+/n_- is 1.22. These numbers are in close agreement with values found on land. The diurnal variation of n_+ has been investigated, and the element has been found to have a flat maximum ranging from about 6 a. m. to 2 p. m. and a minimum about midnight.

(3) The mean ocean value of the specific ionic velocities is 1.30 cm. per second per volt per cm., and is the same for ions of both signs. It is somewhat greater than the values $v_+ = 1.08$ and $v_- = 1.22$ obtained as the means for a number of land stations, but is nearer to the ionic velocities as measured for ions artificially produced in dust-free air.

(4) The mean ocean value for the air-earth current-density is 9.5×10^{-7} E.S.U.

(5) The number of pairs of ions produced per c. c. per second in a closed copper vessel over the ocean shows very little variation with season or location, and there does not appear to be any appreciable diurnal variation in the quantity. The mean absolute value of the number in question is 3.8. It is considerably smaller than the values resulting from corresponding measurements made on land, a result to be expected in view of the absence, over the ocean, of the contribution to the penetrating radiation by radioactive materials.

(6) The average radium-emanation contents found over the Pacific and sub-Antarctic Oceans are respectively 3.3×10^{-12} and 0.4×10^{-12} curie per cubic meter. These values are much smaller than the mean value (88×10^{-12} curie per cubic meter) for the land. They are too small to contribute in a marked degree to the ionization over the ocean, and it is concluded that the reason for the measured ionic densities over land being, if anything, smaller than those over the ocean, is to be found in the greater purity of the ocean air as compared with the land air. The presence of dust nuclei, in fact, increases the number of ions which go into the slowly moving class, and which consequently lose their power of becoming registered in the usual measuring apparatus.

As yet no detailed analysis of the observations has been made with a view to determining the interrelations between the atmospheric-electric quantities and latitude, temperature, humidity, and atmospheric pressure.

SOME DISCUSSIONS OF THE OCEAN MAGNETIC WORK, 1905-1916.

By L. A. Bauer and W. J. Peters.

CORRECTIONS OF MAGNETIC CHARTS.

From time to time, attention has been called to the corrections required for the various magnetic charts to have them conform to the values of the magnetic elements observed on the *Galilee* and the *Carnegie*.[1] Reference to these corrections will also be found in various sections of this volume.

The corrections in the case of the magnetic-declination charts (mariners' charts of lines of equal magnetic variation), for the ocean routes generally traveled, have been usually below 2°, though at times exceeding this amount. Unfortunately, the corrections are frequently of the same sign, or in the same direction, for long stretches at a time. The navigational error is likely, therefore, to be cumulative when the mariner is dependent largely on the correctness of his magnetic-variation charts; this is the case in time of storm or fog, when it is not possible to control the ship's position by observations on the Sun or stars.

In certain parts of the Pacific and the Atlantic Oceans the chart corrections have been about 4°, while in the Indian Ocean they reached 6°, and off the southwest coast of Australia, from 12° to 16° (see p. 328).

The corrections for the charts of the lines of equal magnetic inclination have usually been less than 5°, though amounting in certain regions to 9°.

The corrections for the charts of the lines of equal horizontal intensity have been on the order of 0.005 to 0.015 c. g. s., and have even reached .060 c. g. s. on the most southerly cruises. In general, the corrections were found to be on the order of 2 to 10 per cent.

Erroneous assumptions as to amount and sign of secular changes have been found to be partly, sometimes largely, responsible for the systematic chart-corrections.

A brief summary of the declination corrections in the Pacific Ocean will be found in the September 1915 issue of *Terrestrial Magnetism and Atmospheric Electricity*.

A future volume will contain a detailed investigation concerning the amount and run of the chart corrections. Let it suffice to state here that the chart corrections as found may be attributed to a combination of the following causes: observational error caused, for example, by the use of more or less imperfect instruments, or arising from some other source; erroneous determination, or incomplete elimination of deviation-error produced by the magnetic character of the vessel on which observations were made; erroneous secular-change data as above explained; paucity of observations in a given region; and, finally, local disturbances, near land and over shallow areas. What irregularities may be expected in the isomagnetic lines over the ocean areas in general, is a question often raised, the discussion of which must, at present, be deferred.

A good idea of the extent of the chief magnetic data available to constructors of magnetic charts, before the work of the *Galilee* and the *Carnegie*, may be obtained by examining Plates 23, 24, and 25, showing the tracks of the chief vessels on which magnetic observations were made at sea during the period 1839-1916. The legends on the three respective plates will furnish all required explanations. Of course, no attempt has been made to represent also the data, principally of magnetic declination, obtained by naval and other vessels in the course of their cruises, or in connection with survey-work. The

[1] For tables showing corrections of magnetic-declination charts, see *Terr. Mag.*, v. 15, pp. 57-82, 129-144; v. 16, pp. 133-136; v. 17, pp. 31-32, 97-101, 141-144, 179-180; v. 18, pp. 63-64, 111-112, 161-162; v. 19, pp. 38, 126, 204, 234-235; v. 20, pp. 69-70, 104; v. 21, pp. 15-18, 109-116.

plates serve to exhibit, in a general way, how the cruises of the *Galilee* and the *Carnegie* have been carried out, not only with reference to the other chief expeditions, but also in the fulfillment of the object of securing, within a comparatively brief period, a systematic magnetic survey of ocean areas. On the homeward cruise of the *Carnegie* in 1916–1917 (see broken red lines, Pls. 23 and 24), additional data will be obtained.

Figure 29 shows the corrections of the various magnetic-declination charts for certain portions of the *Atlantic Ocean* at the time Cruise I and the first part of II of the *Carnegie* were carried out. East magnetic declination being given the positive sign, a plus correction, for example, means that the chart-value of east magnetic declination was smaller and of west

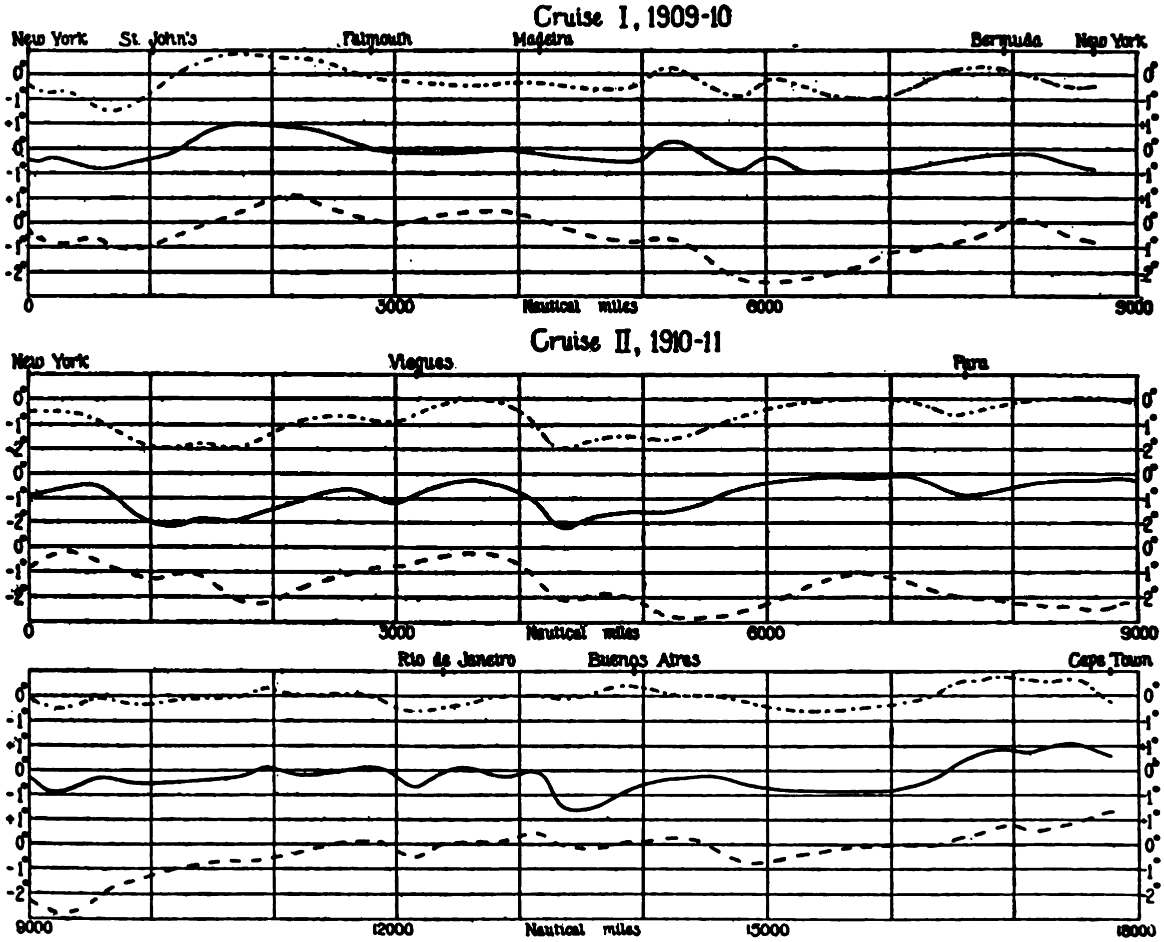


FIG. 29.—Showing Corrections of Magnetic-Declination Charts for the Atlantic Ocean, 1909–1911.

(British Admiralty, -·-·-·-·-·-·-; United States Hydrographic Office, ————; German Admiralty, - - - - - - - - - -.)

magnetic declination larger than the values observed on the *Carnegie*. The *Carnegie's* chief ports of call are shown, as also the distances in nautical miles traversed from the home port, New York. The chart-values used in the construction of Figure 29, as well as of Figures 30–35, were referred to the dates of the *Carnegie's* observations by means of the secular changes shown on the respective charts.

It will be seen that the curves given in Figures 29–35 are usually the same for the various charts, the corrections being generally less than 2°, though in some instances they are more. The peculiar and often systematic run of the corrections for long stretches is well shown by the curves. Figure 30 applies to the regions of the *Atlantic Ocean* traversed

by the *Carnegie* on the homeward portion of Cruise II in 1913, and on Cruise IV in 1915. Figure 31 shows the chart-corrections revealed on Cruise III of the *Carnegie* in the *North Atlantic Ocean* in 1914; during this cruise a high northerly latitude (79° 52′) was reached off the northwest coast of Spitsbergen.

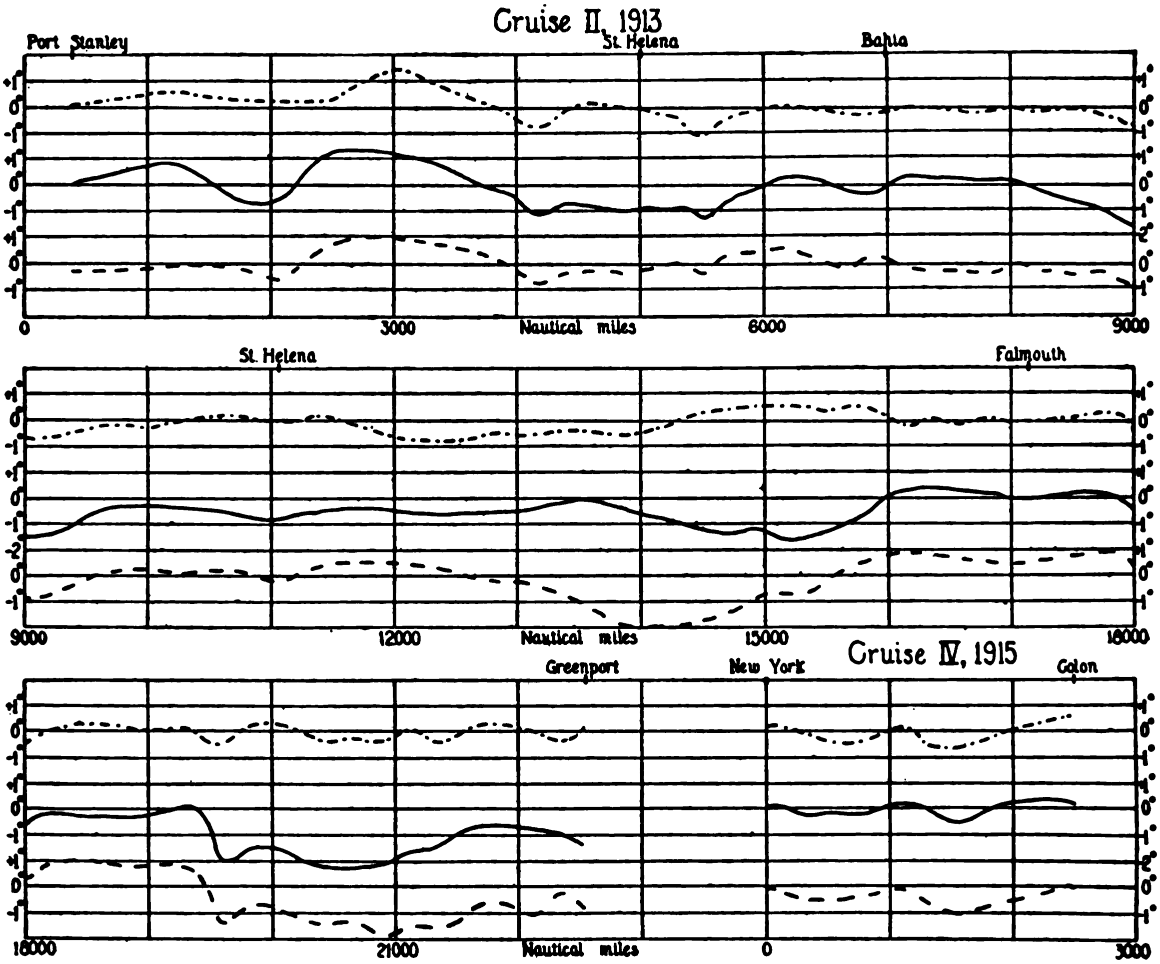


FIG. 30.—Showing Corrections of Magnetic-Declination Charts for the Atlantic Ocean, 1913 and 1915.

(British Admiralty, -·-·-·-·-·-·-·-; United States Hydrographic Office, ————; German Admiralty, - - - - - - - -.)

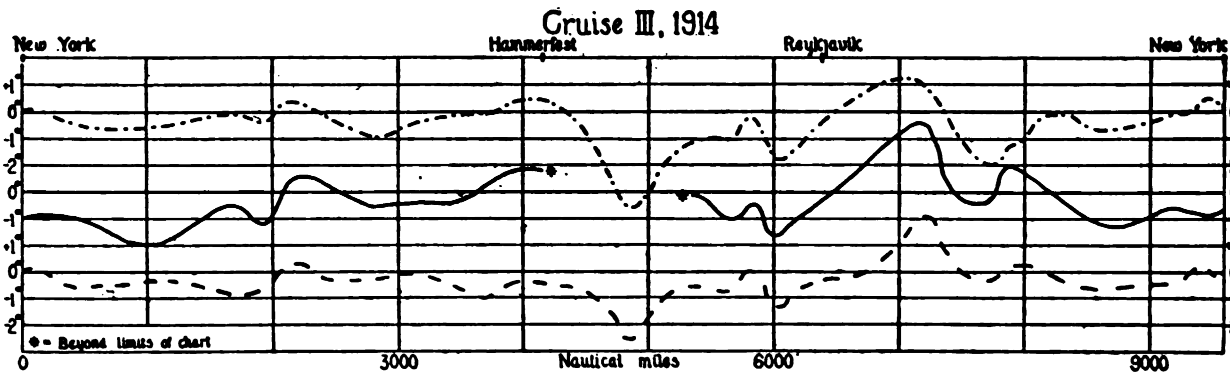


FIG. 31.—Showing Corrections of Magnetic-Declination Charts for the North Atlantic Ocean, 1914.

(British Admiralty, -·-·-·-·-·-·-·-; United States Hydrographic Office, ————; German Admiralty, - - - - - - - - -.)

Figure 32 shows the corrections of the various magnetic-declination charts for the portions of the *Indian Ocean* at the time of the *Carnegie's* circumnavigation cruise (No. II), 1911–1912. It is seen that here the corrections are larger than for Figures 29–31, reaching 4° to 6° at times.

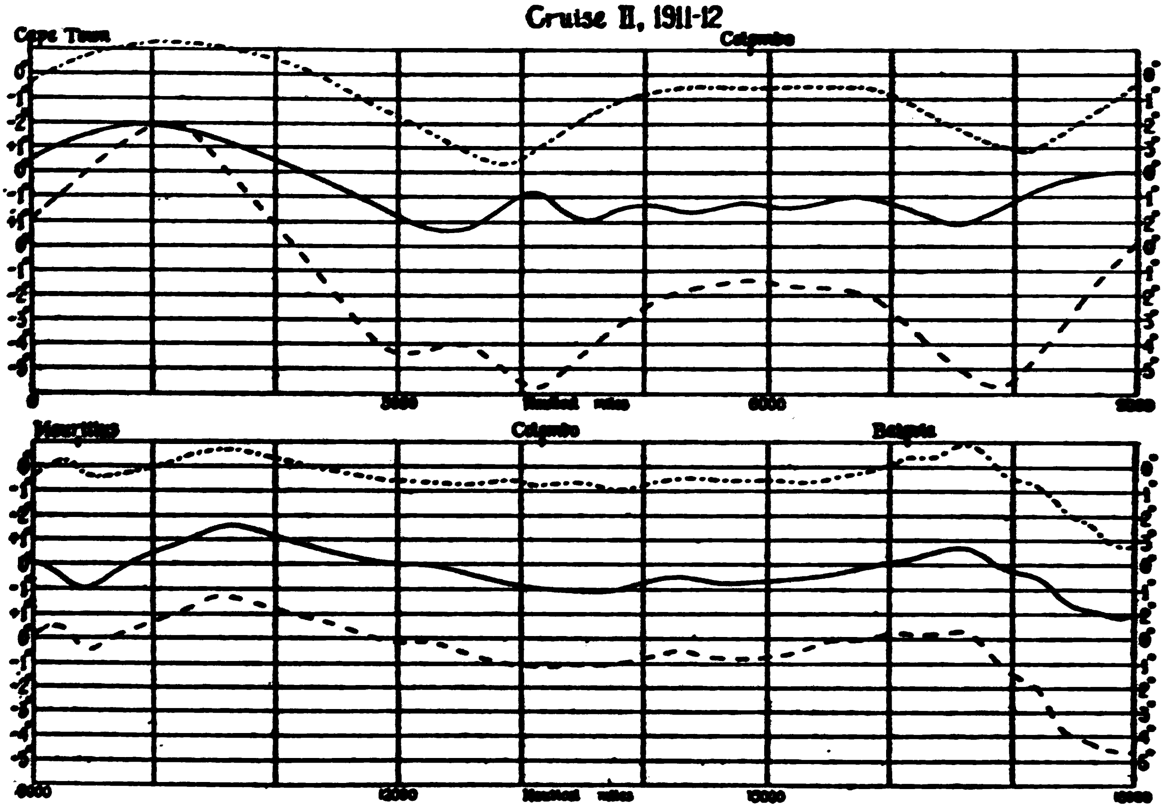


FIG. 32.—Showing Corrections of Magnetic-Declination Charts for the Indian Ocean, 1911–1912.

(British Admiralty, ·-·-·-·-·-·-·-·; United States Hydrographic Office, ————; German Admiralty, - - - - - - - -.)

Figure 33 shows the corrections of the various magnetic-declination charts revealed on the *sub-Antarctic voyage of the Carnegie*, during which she sailed from Lyttelton, New Zealand, on December 6, 1915, and returned to the same port on April 1, 1916 (see pp. 326–330). The omitted portions of the curves apply to the region beyond the limits of the usual magnetic charts. The magnitude of the corrections (5° to 16°) and the rapid change in sign are strikingly exhibited by the curves. The large corrections apply especially to the portion of the Indian Ocean, off the southwest coast of Australia, where the value of the magnetic-declination changes very rapidly. The fact that the largest corrections in the South Indian Ocean (see Fig. 33) are shown by the German Admiralty chart is fully explained by the circumstance that this particular chart was issued before the *Carnegie's* observations in the Indian Ocean during 1911 were available.

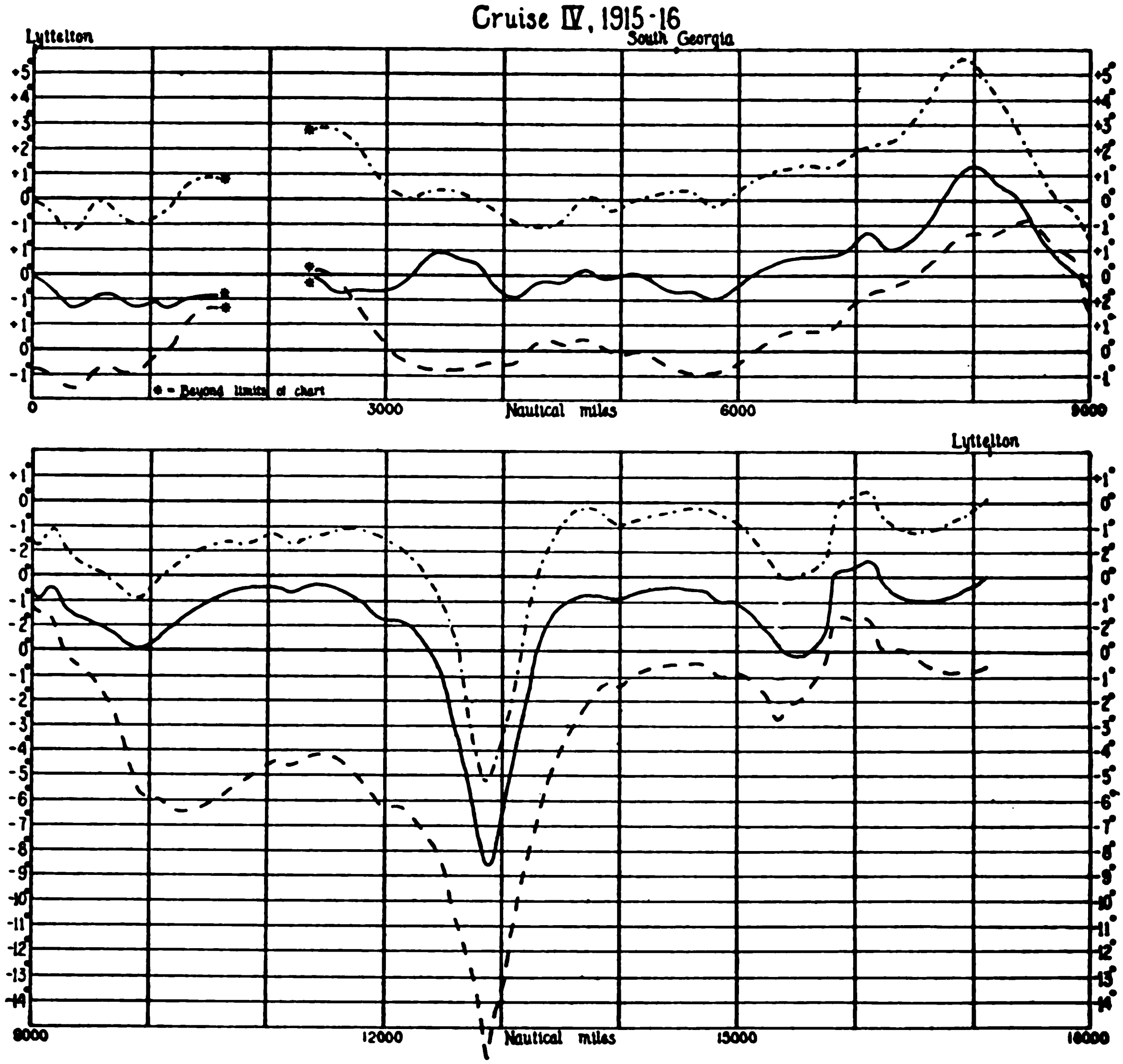


FIG. 33.—Showing Corrections of Magnetic-Declination Charts for the Sub-Antarctic Voyage of the *Carnegie*, 1915-1916.
(British Admiralty, ·-·-·-·-·-·-·-·-·; United States Hydrographic Office, ————; German Admiralty, - - - - - - - -.)

Figure 34 shows the corrections of the various magnetic-declination charts for the portions of the *Pacific Ocean* at the time of the *Carnegie's* Cruise II, 1912. Figure 35 shows the same for Cruise IV, 1915 and 1916. An inspection of the curves indicates that, as the ocean data obtained aboard the *Galilee* and the *Carnegie* became available, improvements were made in the magnetic charts issued by the various hydrographic establishments.

CONCERNING CONSTRUCTION OF NEW MAGNETIC CHARTS.

The construction of the world magnetic charts of the Carnegie Institution of Washington, as based chiefly on the observations of the Department of Terrestrial Magnetism, both on land and sea, is deferred until about 1918. By that time there will be available additional data from the *Carnegie* in the Atlantic Ocean and from the land observers in various parts of the globe. Secular-variation tables may then be successfully constructed for referring all of the accumulated results to some selected date.

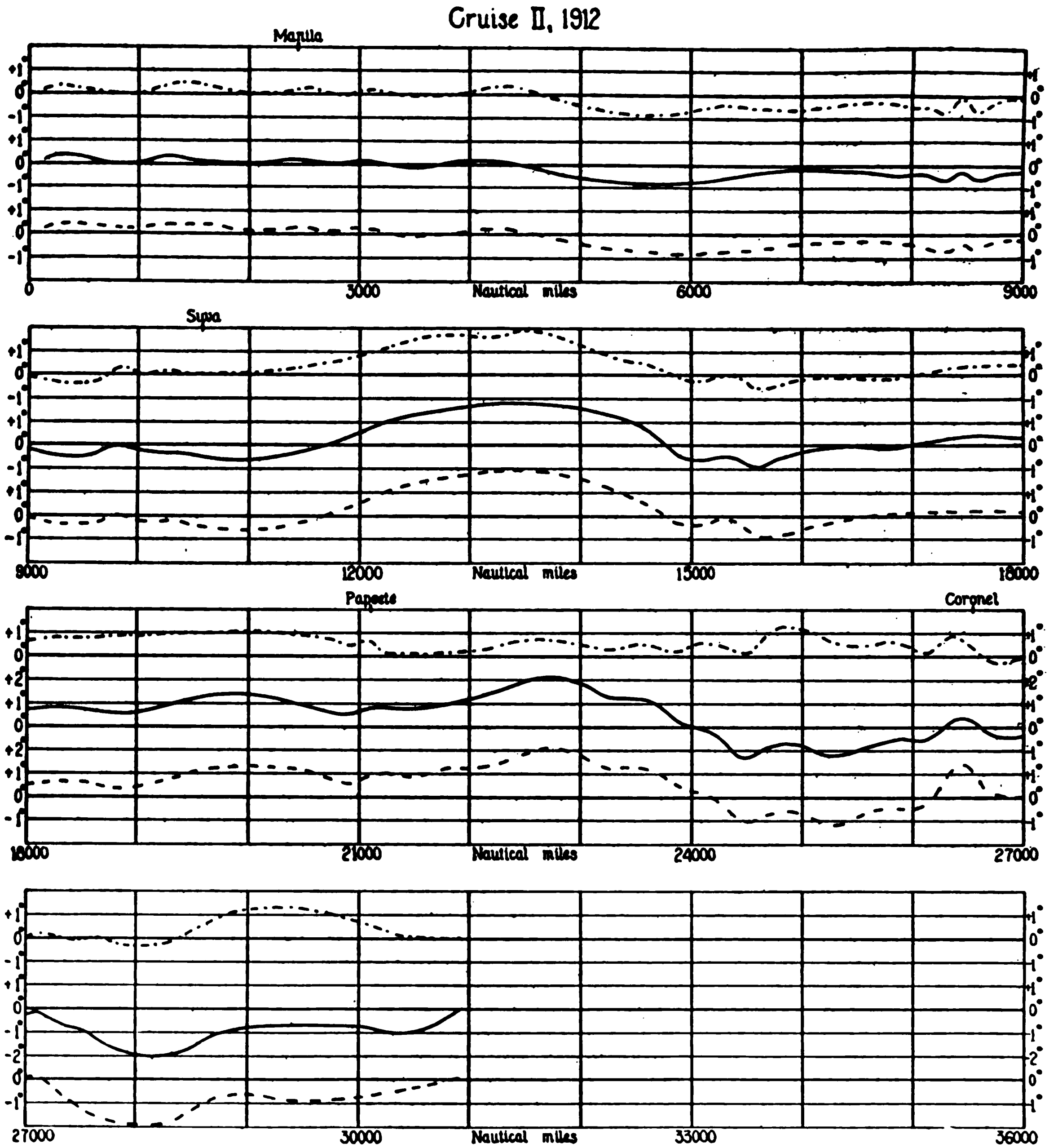


FIG. 34.—Showing Corrections of Magnetic-Declination Charts for the Pacific Ocean, 1912.

(British Admiralty, - · - · - · - · - · - ·; United States Hydrographic Office, ————; German Admiralty, - - - - - - - - -.)

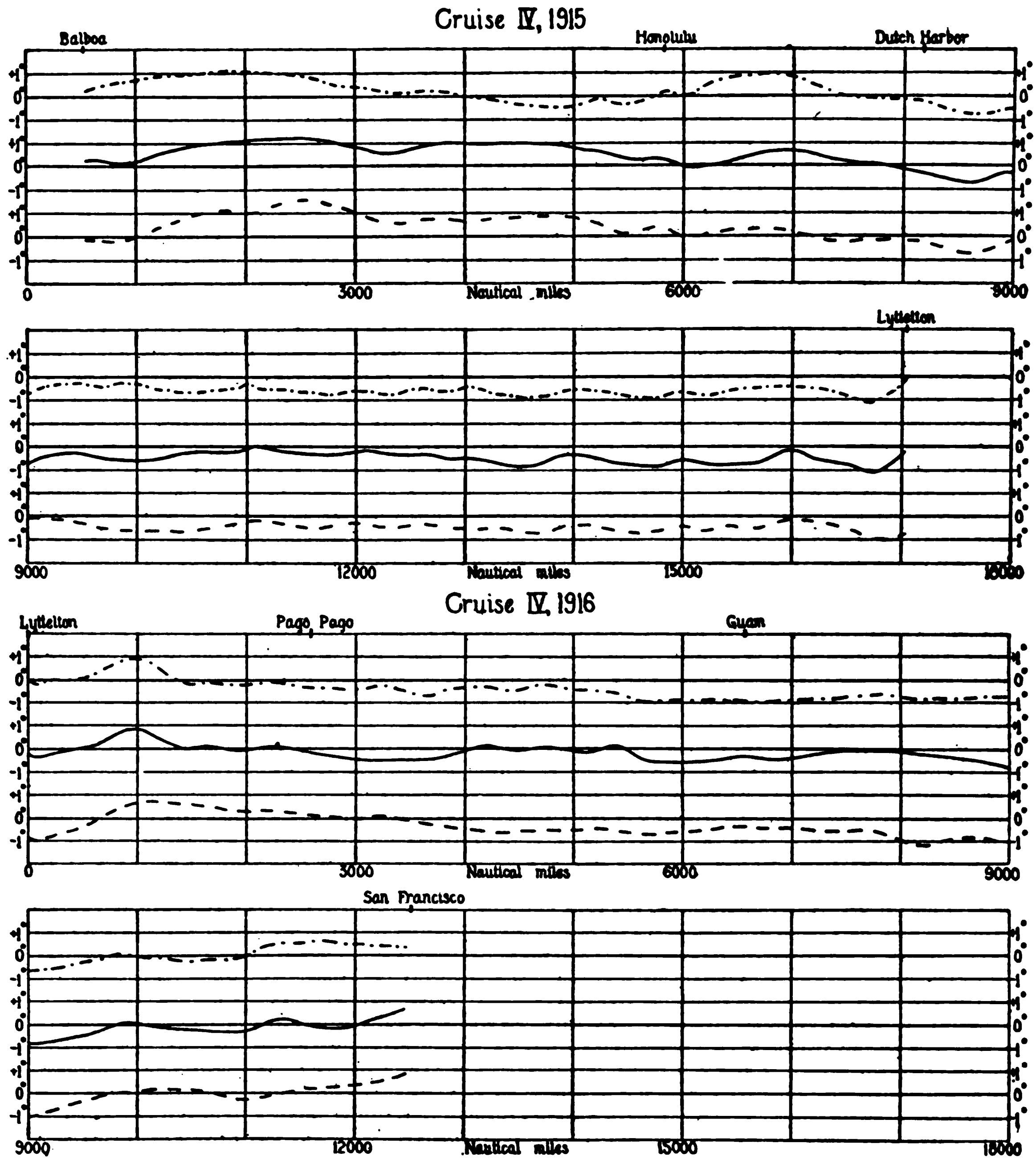


FIG. 35.—Showing Corrections of Magnetic-Declination Charts for the Pacific Ocean, 1915–1916.

(British Admiralty, -·-·-·-·-·-·-·-; United States Hydrographic Office, ————; German Admiralty, - - - - - - - - .)

PRELIMINARY VALUES OF THE ANNUAL CHANGES OF THE MAGNETIC ELEMENTS AS DETERMINED FROM THE GALILEE AND CARNEGIE RESULTS, 1905–1916.

DATA AT INTERSECTIONS OF TRACKS OF VESSELS.

Explanatory Remarks.

The magnetic results of the *Galilee* and the *Carnegie* have been compared from time to time with the values scaled from the magnetic charts in use. As has been seen from Figures 29–35, systematic errors were found which may be explained, at least for the magnetic-declination charts, by a lack of accurate information of the secular changes over the ocean areas. Constructors of magnetic charts have been obliged to rely principally upon the secular changes shown by land observations along the coasts and on the islands, or upon more or less uncertain sea observations, separated often by rather long intervals. Plates 20, 23, 24, and 25 show that during the various cruises of the *Galilee* and the *Carnegie*, a veritable network has been formed by the crisscrossing of their tracks.

Theoretically, every crossing should furnish data regarding secular variation in each magnetic element, but there are practical difficulties in securing accurate values of the annual amounts of the secular variation at sea, which can not be entirely avoided. If the interval of time between the observations of two tracks that cross is very short, it is evident that the secular variation may be masked by observational error. The comparison then serves only as some measure of the accuracy of the results. On the other hand, when the time-interval is sufficiently large the average annual change may be determined with some precision for the time considered; as the annual change itself is a variable quantity, the accuracy of its determination can not, however, be increased *ad libitum* by simply increasing the time-interval, nor can it be assumed that the annual change at the end of the interval is the same as the average value for the elapsed interval.

Another difficulty, peculiar to ocean observations, is that the precise point of a former observation can not usually be reoccupied, and the difficulty is increased when the declination is not determined at the same time and place as the other magnetic elements. In order, therefore, to compare the results of magnetic observations made at two different dates for the purpose of determining the average annual changes, they must be referred to practically the same geographic position, if, as most frequently happens, the values of the magnetic elements are not independent of the geographic position within the area considered. The accuracy of the determination of the annual change is therefore improved by increasing the number of observations within the area considered. There are, however, practical limits to the number of observation-results that may be utilized. If they extend beyond the area over which their changes with geographic position may be considered linear, it is necessary to include in the computation of the value of the magnetic element for some common point, terms containing the latitude and longitude differences to the second degree or more, and the number of unknowns is thus increased; in this case the time and labor which would be required to make a solution are justified only when no more observations are likely to be available for some time to come.

A preliminary investigation of the distribution of the magnetic-declination values over limited areas around some of the intersections of the *Galilee-Carnegie* tracks, shows that a single determination of the declination may occasionally differ many minutes from the normal value as indicated by the remainder of the group. The cause of such abnormal values is not always known; there might have been local disturbance or there might have been abnormal conditions of the ship's motion. Whatever the cause, the inclusion of such a station in a group that is utilized to determine the average annual change, may seriously affect the result sought, especially, if the group is composed of but few units. The presence

of an abnormal value can only be detected when there are a sufficient number of observational results to determine the normal value with fair accuracy.

At sea, the distribution of stations around the track-crossings, or intersections, can not be planned with certainty. Conditions of sea and weather, and the ship's course, combine to crowd or to scatter the magnetic observations irregularly along the tracks followed. Consequently, the determination of the annual change may be strong, depending on many observations for both dates, or it may be weak on account of a paucity of observations at one or the other time.

As new tracks are made, the crossings become more frequent, so that in a few years more the annual amount of the secular variation for a given period may be determined at any desired part of the navigable oceans. *For the present, however, the average annual changes as deduced from Galilee-Carnegie cruises to date, must be considered as preliminary, pending additional information and more complete investigation.*

The preliminary mean annual changes for the three magnetic elements, as determined from the *Galilee* and *Carnegie* results for an interval of four years or more, between August 1905 and September 1916, are given in Tables 96–98 for the Pacific, Atlantic, and Indian Oceans, with the time-intervals for which they apply. The number of observational results from which the annual change is deduced is given for each date and also the least number that occurs in any group. These numbers together with the elapsed time-intervals are some indication of the relative reliability of the corresponding annual change. When the least number is 3, or less, the corresponding value of the annual change must be regarded as weakly determined until future results confirm the linear distribution assumed and the absence of abnormal values.

In these preliminary computations no attempt has been made to eliminate the effects of the diurnal variation of the magnetic elements. In general, at the times selected for the observations, these effects are small. Furthermore, usually the local mean times are about the same for the two dates of comparisons so that the diurnal-variation effects are practically eliminated in taking the differences of the values of the magnetic elements at the two dates.

The annual changes given in Tables 96–98, have been derived by several different methods, briefly described as follows:

a. If the mean geographic positions of the two groups of observations for the two intersecting tracks are practically identical, the mean values of the magnetic elements of each of the two groups are taken as the values at the common point for the respective dates. The difference between the two values of each element, divided by the elapsed time, is taken as the average annual change. It most frequently happens, however, that the mean geographic positions for the two dates do not coincide.

b. The method most commonly used was to arrange in groups the observations made at the intersection of two or more tracks. The mean values of the dates, geographic positions, and corresponding magnetic elements for each group having been determined, the point of intersection of lines joining the mean positions of the two groups of each intersecting cruise was found graphically. By the method of simple ratios and from a comparison of the mean values of date, position, and magnetic elements, as determined for each group, the magnetic element for its corresponding date was deduced for this point of intersection.

c. When two groups as in *a*, or four groups as in *b*, were not available, as, for example, in the case of the observations made on the tracks converging to Gardiners Bay, then a least-square adjustment was made, assuming that the values of the magnetic elements depend upon their geographic position and that the value of an element E, at a point whose latitude and longitude are ϕ and λ, respectively, may be expressed by an equation of the form

$$E = E_0 + y\Delta\phi + z\Delta\lambda \cos\phi$$

in which $\Delta\phi = \phi - \phi_0$, $\Delta\lambda = \lambda - \lambda_0$, and ϕ_0, λ_0 are the geographic coordinates corresponding to the approximate mean value E_0. The terms of second degree and above have been omitted and $\cos\phi$

taken as constant because of the small size of the areas here involved. In order to reduce the observations to a common date, corresponding to the mean date of all the tracks, another unknown w, the secular-variation term, is included in the above equation, and also x, the most probable correction to the approximate mean value E_0, of the element in question at the point ϕ_0, λ_0. We have finally for the observation equation

$$E = E_0 + x + y\Delta\phi + z\Delta\lambda + w\Delta t \qquad (1)$$

in which Δt is the date of observations minus the adopted mean date. In the practical application of this method the weights assigned to the various results in the Tables of Results (see pp. 97–104 and 261–287) have been applied.

d. The values of x, y, and z have sometimes been determined from the data of one track only, or both tracks separately, from the equation

$$E = E_0 + x + y\Delta\phi + z\Delta\lambda \qquad (2)$$

The values of the magnetic elements for some point, usually the mean position of one group, have then been calculated from the x, y, z, and the mean value and mean position of the other group. The values for the different epochs thus become strictly comparable.

The methods *a* and *b* are temporary expedients to obtain approximate values expeditiously. The method *c* is to be preferred, since it has the advantages of combining observations by weights, of exhibiting discordant results, also of indicating thereby whether the groups cover too large an area for the assumption of linear changes; as it involves considerably more time and labor, its general application, however, must be deferred to a later date. Chief assistance in the determination of the present values of the annual changes was rendered by Computer C. C. Ennis.

An inspection of the preliminary values of the annual changes in Tables 96–98 shows that the quantities are of the same general order of magnitude as disclosed by observations on land. As already stated, the discussion of the values is deferred until additional data have been obtained. The annual changes for the declination and inclination are invariably referred to the north-seeking end of the magnetic needle. Thus 6′ W means that the north-seeking end of the compass moved to the west at the average annual rate of 6′ during the period shown in the third column of the tables; 1′ N means that the north-seeking end of the dip needle moved downwards at the average annual rate of 1′ during the period in the third column.

PRELIMINARY AVERAGE ANNUAL CHANGES IN THE MAGNETIC ELEMENTS DETERMINED FROM THE GALILEE AND THE CARNEGIE OBSERVATIONS, 1905–1916.

TABLE 96.—*Average Annual Changes for the Indian Ocean.*[1]

Lat.	Long. East of Gr.	Approx. Dates showing Time-Intervals	Average Annual Change			Number of Values utilized to obtain Annual Change			
			Decl'n	Incl'n	Hor. Int. (Units of fourth dec.) C. G. S.	Decl'n	Incl'n and Hor. Int.	Least Number in any Group	
								Decl'n	Incl'n and Hor. Int.
°	°		′	′					
37.5 S	25.9	1902.4–1911.4	11 E	....	....	10 and 5	....	5	....
25.3 S	60.6	1903.4–1911.6	5 W	....	....	4 6	....	4	....
35.3 S	74.8	1903.3–1911.4	13 W	....	....	7 12	....	7	....
36.0 S	95.4	1911.9–1916.1	17 W	2 S	−7	5 11	5 and 7	[2]5	[2]5

[1]The first three entries of the table are derived from the intersections of the tracks of the *Carnegie* in 1911 with those of the *Gauss* (the vessel of the German Antarctic Expedition, 1902 and 1903); see *Terr. Mag.*, v. 16, p. 136, 1911.
[2]Two groups only.

TABLE 97.—*Average Annual Changes for the Atlantic Ocean.*

Lat.	Long. East of Gr.	Approx. Dates showing Time-Intervals	Average Annual Change			Number of Values utilized to obtain Annual Change			
			Decl'n	Incl'n	Hor. Int. (Units of fourth dec.) C. G. S.	Decl'n	Incl'n and Hor. Int.	Least Number in any Group: Decl'n	Least Number in any Group: Incl'n and Hor. Int.
°	°		′	′					
50.4 N	331.3	1909.8–1914.5	4 E	1 S	0	3 and 3	4 and 5	[2]3	2
49.5 N	352.7	1909.8–1913.7	7 E			5 8		[1]3	
48.4 N	343.0	1909.8–1913.7	8 E	3 S	+5	7 7	4 5	2	2
48.3 N	311.2	1909.8–1914.7	4 E	4 S	+4	7 9	3 6	2	1
46.2 N	346.5	1909.8–1913.7		6 S	+3		7 9		2
42.8 N	299.7	1909.7–1914.8	5 W			5 9		1	
42.7 N	343.9	1909.9–1913.7	4 E	6 S	+5	7 8	4 5	2	2
42.4 N	297.2	1909.7–1914.8		1 N	−4		4 6		2
39.0 N	291.1	1909.7–1915.2	[3]3 W			34 ..		[3]34	
38.1 N	342.8	1909.9–1913.8	6 E	3 S	+1	6 7	4 4	2	2
21.1 N	325.2	1909.9–1913.6	7 W	10 S	0	10 9	7 4	4	2

[1]Three groups only. [2]Two groups only. [3]One adjustment of 34 results; probable error ±1′.5.

TABLE 98.—*Average Annual Changes for the Pacific Ocean.*

Lat.	Long. East of Gr.	Approx. Dates showing Time-Intervals	Average Annual Change			Number of Values utilized to obtain Annual Change			
			Decl'n	Incl'n	Hor. Int. (Units of fourth dec.) C. G. S.	Decl'n	Incl'n and Hor. Int.	Least Number in any Group: Decl'n	Least Number in any Group: Incl'n and Hor. Int.
°	°		′	′					
46.0 N	159.2	1906.7–1916.6		1 N	−2		6 and 7		2
45.9 N	162.8	1906.7–1916.6	6 W			7 and 13		1	
45.4 N	164.1	1906.7–1915.6	6 W	1 S	−2	3 8	6 8	1	2
42.8 N	221.6	1906.8–1916.7	2 E	0	−2	2 10	4 7	[1]2	2
42.0 N	190.4	1907.0–1915.5	4 W	5 S	0	7 9	4 6	3	2
41.2 N	222.3	1907.6–1916.7	2 E	1 S	+1	6 10	6 7	3	2
39.2 N	231.6	1906.8–1916.7	4 E	0	−2	3 7	3 5	1	1
36.7 N	150.5	1906.7–1916.6		2 N	−3		4 3		[2]3
30.3 N	144.1	1906.6–1916.6	3 W	0	−1	8 8	5 4	3	2
27.2 N	199.3	1905.9–1915.5	2 E			8 7		[2]7	
26.4 N	131.0	1907.4–1912.3	0	2 S	+2	6 5	5 8	2	2
19.5 N	218.2	1906.2–1915.4	4 E	1 N	−2	7 12	7 6	3	3
17.6 N	144.3	1906.6–1916.6		1 S	−1		3 4		1
15.3 N	174.6	1907.8–1912.3	5 W	2 N	0	5 6	4 4	2	2
15.3 N	174.6	1912.3–1916.5	3 W	1 S	−7	6 11	4 5	2	2
14.5 N	236.5	1907.5–1915.4		6 N	−1		5 7		2
13.4 N	239.9	1907.8–1915.4	2 E			8 7		[2]7	
11.9 N	244.8	1908.3–1915.3		4 N	−2		4 4		2
7.6 N	164.1	1906.5–1915.7	1 W	7 S	−2	6 12	5 5	3	2
6.0 N	234.0	1907.0–1912.6	6 E	5 N	−2	6 16	6 15	2	2
2.0 N	161.4	1907.2–1915.7	3 W	5 S	−3	5 14	6 8	2	3
0.4 N	246.6	1908.3–1912.6	4 E	4 N	+4	3 5	4 4	[2]3	[2]4
1.5 S	178.6	1906.4–1912.4	2 W	6 S	+1	6 8	6 8	3	3
5.3 S	176.5	1907.2–1912.4	1 W	2 S	−3	4 10	5 7	1	2
11.8 S	216.3	1907.1–1912.7	7 E	0	−3	6 10	6 6	2	2
26.5 S	268.5	1908.1–1913.0	0	4 N	−4	7 8	6 6	3	3
31.0 S	187.8	1912.5–1916.4	4 E	1 S	−6	6 13	6 6	2	3

[1]Three groups only. [2]Two groups only.

ANNUAL-CHANGE DATA AT PORTS.

From the shore magnetic observations at ports of call of the *Galilee* and the *Carnegie*, the results of which are given on pages 105–110 and 296–310, the average annual changes of the magnetic elements may be determined at all ports at which the observations have been repeated at various times, which is often the case. These shore repeat-observations will be utilized in conjunction with the usual land magnetic results, the discussion of which is to be undertaken in a subsequent volume.

DATA FOR GARDINERS BAY AND GREENPORT, LONG ISLAND.

It will be of interest here to obtain some idea of the accuracy attainable in the determination of secular changes with the appliances and methods used in the *Carnegie* work, when the observations are made under the most favorable conditions. For this purpose, the results of observations during swings of the *Carnegie* in Gardiners Bay, 1909–1915, are selected, and comparisons are made with the results of shore observations during 1909–1914 at Greenport, about 8 miles distant from the place of swing, obtained by the *Carnegie* observers using the latest types of magnetic instruments for land work. The results of the observations for Gardiners Bay will be found in the tables of ocean results, pages 261–288, and those for Greenport on pages 298–300. All the results have been corrected for diurnal variation with the aid of the records of the magnetic observatory of the United States Coast and Geodetic Survey at Cheltenham, Maryland, a factor having been applied to refer the corrections to the observation-stations, Gardiners Bay and Greenport.

TABLE 99.—*Results of Magnetic Observations in Gardiners Bay, 1909–1915.*
(Latitude, 41° 06′ N; longitude, 72° 13′ W.)

Date of Observation	Observed Values			Values at 1912.5			Residuals		
	Decl'n	Incl'n	Hor. In.	Decl'n	Incl'n	Hor. In.	D	I	H
	° ′	° ′	c.g.s.	° ′	° ′	c.g.s.	′	′	γ
1909.67	11 22 W	72 07 N	.1828	11 40 W	72 10 N	.1813	+1.2	+0.6	− 4
1910.48	11 25 W	72 07 N	.1825	11 38 W	72 09 N	.1814	−0.8	−0.4	+ 6
1913.96	11 48 W	72 08 N	.1807	11 39 W	72 06 N	.1815	+0.2	−3.4	+16
1914.80	11 48 W	72 14 N	.1801	11 34 W	72 11 N	.1813	−4.8	+1.6	− 4
1915.18	12 00 W	72 14 N	.1798	11 43 W	72 11 N	.1812	+4.2	+1.6	−14
Means				11 38.8	72 09.4	.18134			
Probable errors of a single result							±2.2	±1.4	± 8

TABLE 100.—*Results of Magnetic Observations at Greenport, Long Island, 1909–1914.*
(Latitude, 41° 06′.4 N; longitude, 72° 22′ W.)

Date of Observation	Observed Values			Values at 1912.5			Residuals		
	Decl'n	Incl'n	Hor. In.	Decl'n	Incl'n	Hor. In.	D	I	H
	° ′	° ′	c.g.s.	° ′	° ′	c.g.s.	′	′	γ
1909.49	10 49 W	72 06 N	.1832	11 08 W	72 10 N	.1816	−1.0	+0.8	−18
1910.45	10 57 W	72 06 N	.1830	11 10 W	72 08 N	.1819	+1.0	−1.2	+12
1913.96	11 19 W	72 11 N	.1811	11 10 W	72 09 N	.1819	+1.0	−0.2	+12
1914.78	11 22 W	72 13 N	.1805	11 08 W	72 10 N	.1817	−1.0	+0.8	− 8
Means				11 09.0	72 09.2	.18178			
Probable errors of a single result							±0.8	±0.6	±10

Table 99 contains the results of the sea magnetic observations in Gardiners Bay, 1909–1915, all referred to mean of day. Details regarding conditions prevailing during the swings of the *Carnegie* will be found on page 436. From the values of the magnetic elements in the second, third, and fourth columns, it is found that during the period, 1909–1915, the average changes were as follows:

$$\left.\begin{array}{l}\text{West declination increased } 6'.2 \text{ per annum.}\\ \text{North inclination increased } 0'.9 \text{ per annum.}\\ \text{Horizontal intensity decreased } 0.00053 \text{ c.g.s. per annum.}\end{array}\right\}(3)$$

Table 100 contains the results of the land magnetic observations at Greenport, 1909–1914, all referred to mean of day. From the values in the second, third, and fourth columns, it is found that during the period, 1909–1914, the average changes were as follows:

$$\left.\begin{array}{l}\text{West declination increased } 6'.2 \text{ per annum.}\\ \text{North inclination increased } 1'.4 \text{ per annum.}\\ \text{Horizontal intensity decreased } 0.00052 \text{ c. g. s. per annum.}\end{array}\right\}(4)$$

The agreement between the average annual changes, (3) and (4), is very satisfactory. Taking the mean of the two sets of values, (3) and (4), the observed values in Tables 99 and 100 are referred to July 1, 1912 (1912.5). Thus the quantities given in the fifth, sixth, and seventh columns of the two tables are derived. The remaining columns contain the residuals resulting by the subtraction of the mean values for 1912.5 from the individual values. The H-residuals are expressed in terms of $\gamma = 0.00001$ c. g. s. The probable errors of a single result are given at the bottoms of the two tables. It will be seen that the accuracy reached for the swing observations in Gardiners Bay is satisfactory. That the probable errors of the horizontal-intensity observations are practically the same for the land and sea work here discussed, may be accidental; it should be remembered, however, that the sea values of horizontal intensity are derived from two instruments (the sea deflector and the sea dip-circle) and that the time consumed is about twice that spent on the magnetometer shore-work.

ABSENCE OF MAGNETIC DEVIATIONS ON THE CARNEGIE.

It was explained in the description of the *Carnegie* (pp. 160–163) how every precaution possible was taken in the construction of the vessel and with regard to the installations to insure that, at the various places where the magnetic observations were to be made, there would be no magnetic effects of the kind known as "ship deviations," of sufficient magnitude to be taken into account. In the construction of the auxiliary-power plant, however, it was not found feasible to employ exclusively non-magnetic metal. Thus certain parts of the engine (piston-rings, cam-springs, etc., see p. 162) had to be made of steel. About 3 per cent of the total weight of metal in the auxiliary-power installation is magnetic in its character, but, according to calculation, this 3 per cent could not cause any observable magnetic effects even at the nearest instrument which was mounted inside the after observing-dome (Pl. 9), 41 feet distant from the engine. However, some of the stores which entered into the equipment of the vessel for her long voyages, for example, the tin cans containing provisions, were also of a magnetic character, and that, too, of a variable extent during a voyage. Such stores were stowed in the extreme after part of the vessel, at least 51 feet from the nearest observing-dome.[1] Then, again, there were the numerous magnets

[1] Special tests made at the laboratory of the Department in Washington, May 7, 1916, showed that the maximum quadrantal deviation in declination that might be expected as the result of a largest number of tin cans likely to be in the provision storage-space on the *Carnegie* at any one time, at the distance of the nearest magnetic instrument, would be less than 0°.02 or less than 1′. An effect of this minor order of magnitude would be practically beyond the limits of accuracy of the ocean observations, though it could be determined, were it worth while, from a number of swings in smooth water and in a region of no local disturbance.

belonging to the various magnetic and electric instruments for work at sea and on shore, and, furthermore, the steel and iron tools required by the engineer and the mechanician. These magnetic materials were also stored aft; the general store room for the magnetic instruments and the storeroom for the tools are shown in Figure 9, middle plan, page 162. Hence, in the aggregate, there might be considerable magnetic material at any one time in the after part of the vessel. While, according to calculation, it did not seem possible that under any conditions likely to be encountered on probable cruises of the *Carnegie* there would be observable effects from the total mangetic material, it was decided to control this matter *observationally*. Accordingly, from time to time, complete series of magnetic observations were made while the *Carnegie* was being swung just as though she were a magnetic ship, in fact, observing just as had to be done so frequently in the *Galilee* work.

These "swing observations" of the *Carnegie* were made in Gardiners Bay, usually at the beginning and end of a cruise, at ports where it was known from previous observations there were no pronounced local magnetic disturbances, and occasionally at sea. Possibly in the course of a year there were from 6 to 10 of these special series of observations, the stations varying considerably in magnetic latitude.

In a later volume there will be brought together the results from all "swing observations" for the various cruises of the *Carnegie*. It must suffice for the present purpose to give only those derived from the Gardiners-Bay swings, 1909-1915, in latitude 41° 06′ north and longitude 72° 13′ west of Greenwich. The results for each heading of ship are the means from the observations on the port-helm swing and on the starboard-helm swing. The details regarding the various swings are as follows:

1909. The vessel was swung on September 1 and 2, 1909, just before sailing on her first cruise (Cruise I, see pp. 164–165). Owing to inclement weather on the return of the *Carnegie* in February 1910, the "swings" in Gardiners Bay were omitted.

1910. The *Carnegie* was swung on June 22, 23 and 25, 1910, at the beginning of the long circumnavigation cruise of 92,829 miles (Cruise II, see pp. 165–170).

1913. These swing observations were made on December 15 and 16, 1913, after the *Carnegie's* return from Cruise II.

1914. The *Carnegie* was swung on October 16, 18, 19 and 20, 1914, after her return from the extreme northerly cruise (Cruise III, see pp. 170–171).

1915. The swing observations were made on March 7 and 8, 1915, as the *Carnegie* began the present cruise (Cruise IV, see pp. 172–176).

The vessel was swung by her own engine or with the aid of a tug. Information regarding the general method of observation followed may be obtained by reference to extracts from Director's instructions (see pp. 317–318). If no interruption occurred because of unfavorable conditions, the total time consumed for a complete swing of 8 headings, with both helms, averaged about 1 hour for declination, and about 3 hours for inclination and intensity, or about double the time taken for the usual magnetic observations at sea. For Cruises I and II, the *Carnegie* was in command of W. J. Peters, and for Cruises III and IV, J. P. Ault was the commanding officer. Various observers have taken part, the same magnetic element having generally been observed by different individuals and often with different instruments from year to year.

The residuals given in Table 101 have been obtained by subtracting the mean value of the observed magnetic element for the 8 headings of the ship, from the values for the individual headings. The plus sign is given the declination (D) when east and the inclination (I) when the north-seeking end of the dip needle is below the horizon; the horizontal intensity is always positive. Diurnal-variation corrections were applied to the observations on the various headings in order to refer all values to the same time. These corrections were obtained from the results at the Coast and Geodetic Survey Magnetic Observa-

tory at Cheltenham, Maryland, with an approximate factor applied to those for declination to refer them to Gardiners Bay.

An inspection of the figures in Table 101 shows, for each year the swing observations were made, that the residuals are small; for D and I, they generally are less than 0°.1, and for H, usually less than 0.0005 C.G.S. The residuals are, in fact, on the order of the error of observation.

TABLE 101.—*Residuals from Magnetic Observations on the Carnegie during Swings of Vessel in Gardiners Bay, 1909–1915.*

[The residuals are expressed in minutes of arc for declination and inclination, and in units of the fourth decimal C.G.S. for horizontal intensity. A plus sign means a deflection of the north-seeking end of the magnetic needle towards the east or downwards; it also signifies an increased value of horizontal intensity.]

The observations were found to be of such an order of accuracy as to warrant a separation of the results for the port-helm swing and the starboard-helm swing. When this was done, it appeared at first that there was some evidence of small ship-deviation effects. However, when the results were analyzed, it turned out that the effects were to be ascribed to small local disturbances at the place of swing, in Gardiners Bay, of the same nature as those shown by magnetic observations on islands close by. While the vessel was swung around the anchored buoy, she would pass over somewhat different "bottom" or ground, the area of swing being covered by a circle of about 2 or 3 miles diameter, and the average depth of the water being about 6 fathoms.

The *final conclusions* were:

1. That the residuals from the swing observations in Gardiners Bay could be fully explained by errors of observation and by small local irregularities in the Earth's magnetic field within the region of the swings.

2. That if there are outstanding effects to be ascribed to any magnetic material on the *Carnegie*, they are of such a subordinate magnitude as not to require being taken into account in the observational, or in the computational work.

Possibly no further testimony is needed as to the perfection reached in the ocean magnetic work on the *Carnegie* than that afforded by Tables 99 and 101. It is seen that, under favorable conditions of sea and weather, it is possible, with the instrumental appliances and methods used on the *Carnegie*, to make magnetic observations approaching in accuracy those made ashore on fixed supports.

GREATER PROBLEMS OF THE EARTH'S MAGNETISM.

Investigations relating to the settlement, as far as possible, of some of the outstanding questions of fundamental importance to theories concerning the origin of the Earth's magnetic field are in progress. Final reports and announcement of definite results must be deferred, however, until the accumulated magnetic data on land and sea have all been referred to the same date.

One of the so-called "greater problems of the Earth's magnetism" is the determination of the various systems of magnetic forces which together make up the total terrestrial magnetic field as observed on the Earth's surface. From previous mathematical analyses of the Earth's magnetic field, notably that of Adolf Schmidt, it would appear that the major portion (about 95 per cent) of the field must be ascribed to systems of magnetic or electric forces *below* the Earth's surface. The remaining portion (about 5 per cent) of the field may have to be ascribed to systems of forces, capable of producing magnetic effects, which exist in the regions *above* the surface. These external systems may, for example, consist partly of electric currents circulating overhead, parallel to the Earth's surface, and partly to systems of electric currents passing perpendicularly through the surface. The latter external system is a so-called "non-potential system"; the definite determination of its existence, or non-existence, is a matter of interest and importance with reference both to the subjects of terrestrial magnetism and atmospheric electricity. The solution involves the computation of the line-integral of the magnetic force around a closed path on the Earth's surface. An inspection of Plate 20, or of Plates 23–25, will show how the cruises of the *Galilee* and the *Carnegie* have been executed with the special view of having numerous closed circuits, comprising both large and small areas. The desired line-integrals may, therefore, be computed, when all data have been reduced to a common date, for areas in various parts of the Earth, and also for parallels of latitude completely around the Earth.

The accurate determination of the first of the external systems mentioned (that possibly caused by overhead electric currents), will be of fundamental importance, especially, if it should prove possible also to ascertain definitely how the system changes with lapse of time.

Owing to the inaccuracies of the magnetic charts, or of the magnetic data on which previous investigations have been based, much uncertainty prevails as to the precise reliability of the conclusions reached by past investigators. Thus Schuster, when referring recently to the solution of some of the vexed questions, says: "This demands a more accurate survey of the Earth as a whole than we possess at present, and we look forward to the magnetic survey of the Carnegie Institution of Washington for the required data."

Some studies have likewise been made of the causes which produce the manifold complexities of the Earth's magnetic field—what forces, for example, cause the geographic departures from the simple or uniform type of field. It appears that these "geographic variations," represented by the higher harmonics of the potential expression used to express mathematically the major portion of the terrestrial field, are not of the heterogeneous character they would be if caused chiefly by the distribution of land and water, or by lack of homogeneity in the constitution of the Earth.

The precise characteristics of the phenomenon of the secular variation of terrestrial magnetism is of fundamental importance in connection with theories of the origin of the Earth's magnetic field. The definite limitations imposed by the variations in the Earth's magnetic field, both of the periodic and aperiodic kind, and the departures of the field from the simple uniform type, are too frequently overlooked. Most theories, for example, are found inadequate when the attempt is made to explain, besides the origin of the field, the secular variation, as it is actually observed.

INDEX FOR THE GALILEE MAGNETIC WORK.

[The page-references in heavy type refer to pages on which numerical results of magnetic observations occur; those in italics refer to pages giving descriptions of land magnetic stations.]

INDEX FOR THE CARNEGIE MAGNETIC WORK.

[The page-references in heavy type refer to pages on which numerical results of magnetic observations occur; those in italics refer to pages giving descriptions of land magnetic stations.]

INDEX FOR THE ATMOSPHERIC-ELECTRIC REPORT.

[The page-references in heavy type refer to pages on which numerical results of atmospheric-electric observations are given.]

The Carnegie's House Flag